SPS LABORATORIES
Standard Pressed Steel Co.
Jenkintown, Pa.

INVESTIGATION OF ADVANCED HIGH STRENGTH ALLOYS USED IN WEIGHT REDUCTION OF THE SATURN V THRUST STRUCTURE

by

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Phase I Report

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FOREWORD

The work accomplished to generate the information enclosed in this report was performed under Contract NAS 8-20158 by the SPS Laboratories of Standard Pressed Steel Company, Jenkintown, Pennsylvania.

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ABSTRACT

This report represents the completion of Phase I for Contract NAS8-20158. This phase was conducted to determine the feasibility of beryllium for high strength blind and semi-blind fasteners.

The investigation covered the history of beryllium fasteners and materials, the present state-of-the-art in the production of beryllium fasteners and problem areas that may be encountered in the production of beryllium fasteners.

The investigation showed that semi-blind and blind fasteners of beryllium are feasible with ultimate strength on the order of 75,000 psi and shear strengths on the order of 65,000 psi. A planned approach for the development of these fasteners is presented.

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SECTION I

INTRODUCTION

This contract was initiated to find possible weight reductions for the Saturn V Thrust Structure through the use of light weight, high strength materials for mechanical fasteners. The material chosen for investigation was beryllium as high strength fasteners of titanium and steel were well covered in other work conducted for the National Aeronautics and Space Administration.

Beryllium has the structure advantages of a high strength-to-weight ratio, a high Young's Modulus and high fatigue life. The disadvantages of the material are the low ductility and attendant notch sensitivity, poor crack propagation characteristics and high initial cost. The high cost of weight on aerospace vehicles makes it imperative that beryllium be investigated for use as structural fasteners.

This program was initiated to investigate the usage of beryllium fasteners. The approach to the program is in four phases:

Phase I	-	Feasibility Study
Phase II	-	Development
Phase III	-	Evaluation of Beryllium Alloys
Phase IV	-	Fabrication and Testing

The first phase, which has been completed and the results of which are included in this report, was to run a feasibility study on the use of beryllium for high strength blind and semi blind fasteners. The property goals of the finished fasteners were:

Ultimate Strength - 75,000 psi
Shear Strength - 65,000 psi
Endurance Strength @ 10^6 Cycles - 45,000 psi

The feasibility study itself was broken down into:

Beryllium Fastener History
Production of Beryllium Fasteners - Present State-of-the-Art
Problem Areas and Planned Approach for Solving Problem Areas

The availability of each, practices, specifications, problems, and suggestions for solving the problems were all noted as part of the study.

Subsequent phases will be covered with the development of semi-blind and blind fasteners, the evaluation of the best available beryllium grades for these fasteners, and finally the fabrication and testing of a production size lot of the developed beryllium bolts.

SECTION II

BERYLLIUM FASTENER HISTORY

The first research on mechanical fasteners of beryllium material was conducted at SPS Laboratories during 1957-1958. This work concerned itself with thread properties of a limited amount of commercially pure beryllium. This was a natural projection from titanium mechanical fasteners which were being used in great quantities at that time. There was no better beryllium rod stock for fasteners than the commercially pure beryllium available at that time.

Early in 1959, the Fabrication and Components Branch in the Manufacturing and Materials Technology Division of AMC Aero. Systems Center, Wright-Patterson Air Force Base, Ohio took an interest in the possibilities of using beryllium for light weight fasteners. A Request for Proposal was issued with the subsequent award of a beryllium fastener development contract to SPS Laboratories.

The result of this contract, AF33(600)-39728, was Report No. AMC TR60-7-807 showing the successful development of hexagon head shear bolts and their mechanical properties. These properties were used to establish the target properties for this program. The beryllium materials used in the Air Force program were provided by Beryllium Corp. and Brush Beryllium.

The next program on beryllium fasteners was SPS Laboratories' in-house financed work which resulted in SPS Laboratories Report No. 397, "Beryllium Shear Bolts Flush Head BFT 12 and BFH 12 Protruding Head BHS 12 60,000 PSI Minimum Shear Strength". Data on hexagon head and 100° flush head shear bolts were presented on three heats of beryllium material. The strength-to-density ratio of these bolts was over 1,100,000 psi/pound/cubic inch in tensile and almost 1,000,000 psi/pound/cubic inch in shear. These strength values exceeded those of available 4Al-4Mn titanium and alloy steel bolts. Both titanium and steel have moved to higher strengths since 1961 and are again ahead of beryllium.

After the 1961 work very little research and development work in beryllium fasteners was conducted. Some work was done on tapping beryllium nuts and SPS K-2 Lubricant was found to be a very successful anti-gallant and lubrication for the tightening of beryllium nut and bolt combinations. Some production quantities of fasteners were sold for nuclear engines and the Agena B Program, but not much else was accomplished. Current beryllium structural test programs have not included beryllium fasteners for their weight saving capability primarily due to high cost and non-availability of a variety of beryllium structural fasteners.

SECTION III

PRODUCTION OF BERYLLIUM FASTENERS
PRESENT STATE-OF-THE-ART

A study was conducted to determine the present state-of-the-art in producing beryllium fasteners with reliable properties. The areas investigated during the study were beryllium suppliers and materials, beryllium fastener manufacturers, manufacturing procedures and tests to determine the reliability of a fastener.

A. BERYLLIUM SUPPLIERS

At present, there are four companies capable of producing beryllium materials for fastener fabrication. These companies are:

1. Berylco Corporation (Berylco)
   Hazelton, Pennsylvania 18201

2. The Brush Beryllium Company
   17876 St. Clair Avenue
   Cleveland, Ohio 44110

3. Beryllium Metals and Chemical Corp. (Bermet)
   500 Fifth Avenue
   New York, New York 10036
   A subsidiary of Lithium Corp. of America

4. General Astrometals Corp.
   320 Yonkers Avenue
   Yonkers, New York 10701

B. BERYLLIUM MATERIALS

During the course of the Air Force Beryllium Bolt Program in 1960, Berylco and Brush both supplied special grades which could be forged and thread rolled. These had base material properties of approximately 90,000 psi ultimate tensile and 65,000 psi shear strengths.

Since the Air Force Program, neither Berylco nor Brush have concentrated any effort in the development of an improved beryllium fastener material primarily because a demand did not exist. Furthermore, Berylco indicated that they could not guarantee to duplicate the same material previously evaluated. Brush expressed that they could guarantee the shear strength while Bermet and General Astrometals were willing to quote on a best efforts basis.

Bermet had little history in high strength structural beryllium, but to be considered for this program they went into a development program in conjunction with Nuclear Metals, division of Textron, Inc. West Concord, Mass. Three grades were to be extruded from 1 1/2 inch diameter by 6 inch long billets. Twenty-two to one reduction ratios were used to get to final stock size of .290. One foot samples of each of two grades would be supplied to SPS Laboratories, the third grade was dropped.

General Astrometals is another company which had no prior experience in supplying beryllium fastener stock. They offered to supply material on a developmental, best efforts basis. In order to participate in the program, General Astrometals supplied a 48 inch sample of 3/4 inch round material.

Berylco suggested three grades of beryllium, but one of these - a special forging grade - did not meet the minimum target requirements of 65,000 psi shear strength. One of the lots called PX-12 was to be a duplicate of the high strength grade used in the 1960 Air Force Program. This grade had a beryllium oxide content of 1.2% maximum. The third grade suggested was a low oxide, cast material which would be extruded and drawn to the size needed for this program. The mechanical properties were to be on a best effort basis.

In addition to the straight beryllium grade, Berylco offered data on Lockalloy extrusions showing very low strength. Because of the high beryllium content, the same protective machining methods were required for Lockalloy while ductility and price remain the same as for standard beryllium grades. For these reasons Lockalloy will not be considered for this program, but a constant watch will be kept on the developmental advances of this new alloy. Some of the data on Lockalloy is in Table I.

Berylco also provided some insight into their capability to supply high strength beryllium with some data from an Air Force Program, AF33(657)-271. This program is for development of data on .005 inch diameter wire, but some data at 3/8 inch diameter is provided in Table II.

Brush Beryllium Company had nothing new to offer for improved beryllium fastener material. They quoted on supplying material as used in the SPS Laboratories 1961 Air Force program but with a guaranteed shear strength of 65,000 psi.

C. BERYLLIUM FASTENER MANUFACTURERS

At the beginning of this program several prominent aerospace fastener manufacturers were contacted to determine who were manufacturing beryllium fasteners and what other information might be offered. Of the firms contacted only the Precision Fastener Division of Standard Pressed Steel Co. quotes, makes and sells beryllium fasteners. The companies contacted were:

Briles Manufacturing Co.
E. Grand & Kansas Ave.
El Segundo, California
Comment - Do not plan to make and no experience.

Camcar Division of Textron
18th & Kishankee Ave.
Rockford, Illinois
R. R. Blomberg
Comment - Do not make now, but looking for possible future product.

Hi Shear Corporation
2600 West 247th Street
Torrance, California
Mr. E. Hatter
Comment - Do not make now or plan to in the immediate future.

Standard Pressed Steel Co.
Precision Fastener Division
Jenkintown, Pa.
Comment - Catalogue item

Voi-Shan Manufacturing Co.
8463 Higuera St.
Culver City, California
Mr. D. Anderson
Comment - Not making now, but did in-house development 3 years ago.

D. FASTENER CONFIGURATION

The only company that had beryllium bolts as a catalogue item was the Precision Fastener Division of Standard Pressed Steel Co. These were hexagon head shear bolts and the 100° flush head bolt with either Torq Set or Hi Torque drive. Figures 1 and 2 show the drawings of the bolts covering diameters to .375 inches.

There are no blind bolts, semi-blind bolts, rivets or nuts available on the market.

E. MANUFACTURING OF FASTENERS

The most comprehensive evaluation of threaded fasteners fabricated from beryllium material was conducted by Standard Pressed Steel Co. for the Air Force under contract AF33(600)-39728 (Ref 1). Aside from this evaluation and some in-house work conducted by Standard Pressed Steel Co., the investigation showed that very little work has been concentrated in the area of beryllium threaded fasteners. Nevertheless, the reported results of the evaluation contained valuable information for the fabrication and testing of beryllium fasteners. They included the following:

Available materials
Establishment of inspection methods for bar stock
Establishment of manufacturing methods for beryllium

1. Available Materials

There is presently available beryllium material which can be fabricated into fasteners. Ultimate strengths of these materials are on the order of 100,000 psi.

2. Manufacturing

Standard manufacturing equipment was used for the fabrication of beryllium fasteners. These were modified only by the addition of suitable exhaust systems to keep the toxic materials to a minimum in the work area.

NAS 464 configuration bolts were fabricated from Berylco HPA ground, extruded bar stock and Brush extruded QVM bar stock.

a. Forging

Optimum forging temperature for the forming of the hexagon heads was 1450°F to 1500°F. At temperatures lower than 1450°F cracks were found in the head and often the head did not completely fill out. At the higher temperatures above 1600°F the material burned, formed head cracks, and chipped on the hex corners because of oxidation. The forging dies used were the same as those for a steel NAS 464 bolt.

b. Machining

Turning, center drilling, pointing and thread chasing were accomplished on a South Bend ten-inch engine lathe. K-6 carbide tools were used for these operations; and for the turning operation, a feed of 120 surface feet per minute was employed. The speed could have been increased but optimum chip removal required this lower turning rate. In any event, the machining of beryllium presents no problem other than health hazards which are adequately controlled by proper exhaust systems.

c. Grinding

Grinding was accomplished on Brown and Sharpe Grinders. Specimens and bolts were ground on centers but without a coolant to facilitate dust collection by the exhaust system. The heat generated was insufficient to cause cracking. The material can be centerless ground using the mandatory safety precautions.

d. Thread Rolling

The rolling of threads on beryllium material was accomplished without any difficulty in the fabrication of beryllium bolts. They would be definitely preferred over bolts with machined threads. The residual stresses induced by thread rolling greatly increased the mechanical properties of beryllium bolts.

Thread properties were also markedly increased by increasing the root radius and decreasing the thread depth from 83 1/3% to 55%. The tensile strength of bolts with 55% rolled threads was 50% higher than 55% machined threads. The increase in fatigue strength for 1/4 and 5/16 inch diameter fasteners is shown in Charts 1 and 2.

Thread rolling of ground beryllium bolt blanks was accomplished with an A-22 Reed Cylindrical Die Thread Rolling Machine employing three dies. Threads were formed by die pressure exerted on the ground blanks. The thread profile was NAS 464 drawing. Dust collection units were not required because there was no metal removal, just metal movement.

e. Surface Treatment (Etching)

Surface treatment or etching of finished bolts greatly increased the tensile and shear strength and fatigue life. Double shear strength of unetched ground blanks was 20,000 psi compared to 60,000 psi for ground and etched blanks. Brittle failures were noted for unetched blanks, while ductile failures were noted for the treated blanks. Hence, the surface treatment of finished beryllium bolts is a prerequisite for optimum properties. The etchant used for surface treatment was as follows:

100 grams chromic acid (anhydride)
77 milliliters phosphoric acid
10 milliliters concentrated sulphuric acid
50% by volume water

F. MECHANICAL PROPERTIES

1. Double Shear

The double shear strength of the shanks of beryllium bolts was over 60,000 psi, or more than 65% of the strength of the base material. Steel and titanium bolts have a double shear strength of only 60% of the strength of the base material. On a strength per density basis the beryllium bolts were equivalent to alloy steel bolts of about 400,000 psi and 4Al-4Mn titanium bolts of about 200,000 psi.

The program substantiated that the bolts had to be surface-treated to give a ductile double shear failure. The surface treatment also doubled the shear strength when compared to ground beryllium as shown in Charts 3 and 4.

On a strength-to-weight basis, the surface treated beryllium bolts were 1.6 times higher than titanium bolts with a 172,000 psi tensile strength and 2.6 times higher than steel bolts heat treated to about 200,000 psi. In other words, beryllium fasteners would have to be replaced by titanium bolts weighing 1.6 times as much or by steel bolts weighing 2.6 times as much to get the same strength in the transverse direction.

2. Tensile

The ultimate tensile strength of the beryllium bolts was over 70,000 psi with failure occurring at the thread runout. The strength of the bolts exceeded 70% of the strength of the base material. This is acceptable for shear configurations. There is no evidence available to indicate that the 70% proportion would hold true for stronger beryllium materials. The tensile strengths of NAS 464 configuration bolts fabricated from Berylco HPN and Brush QVM beryllium are shown in Charts 5 and 6. The bolts were tested with 2024-T4 aluminum hexagon nuts.

On a strength-to-weight comparison, the beryllium bolts exceeded the ultimate tensile strength of similar configurations of titanium by 10% and steel by over 60%. This is shown in Tables III and IV. However, it should be noted that tension bolts fabricated from beryllium would not be recommended at this time because of the high degree of notch sensitivity for this material.

3. Fatigue

The fatigue endurance limit of the beryllium fasteners was 45,000 psi for the Berylco bolts and 50,000 psi for the bolts fabricated from Brush material. This compares to 60,000 psi for titanium and 20,000 psi for steel bolts.

The endurance limit of beryllium was twice titanium and nearly ten times steel when compared on strength-to-weight ratios. This means twice the weight of titanium and ten times the weight of steel would be required to get the same clamping force as provided by beryllium fasteners. These results are in Charts 7 and 8.

The S-N curves, shown in Charts 9 and 10, on beryllium fasteners are very flat and indicate a wide variance of results above the endurance limit. Since in most cases the load level above the endurance limit exceeded the yield point of the bolt, wide scatter would have to be expected. The use of beryllium fasteners would have to be confined to loads under the endurance limit to get high reliability.

4. Torque-Tension

The load induced in the beryllium bolts for a given torque was less than that induced in steel or titanium bolts. Charts 11 and 12 show the torque-tension curves for two sizes of beryllium bolts.

5. Ductility

The base beryllium material exhibited little longitudinal elongation. The Brush material had 3% and the Berylco had 6.5%. This is less less than desirable for full control during forging. The reduction of area was 5.6% for theBrush material and 10.0% for the Berylco material.

The two factors, elongation and reduction of area, together indicate that beryllium is a brittle material. Because of the brittleness inherent in the material, extra precautions had to be taken in manufacturing and testing the bolt.

G. INSPECTION METHODS

1. Bar Stock

For incoming material, the two most successful methods consisted of fluorescent penetrant inspection and dye penetrant inspection with the former proving the easiest and best method. Very tight cracks could be determined by these methods. Both methods require a surface treatment of a light etch prior to inspection. This is to remove any material that may be covering defects such as cracks and seams since the metal beryllium has a tendency to smear during machining. The etchant used was the same as that listed under surface treatment. The inspection processes were as follows:

a. Fluorescent Penetrant Inspection

1. Etch .003 inches per surface
2. Dip in solvent for 25 minutes
3. Clean off solvent
4. Dip in developer for 10 minutes
5. Dry
6. Inspect under black light

b. Dye Penetrant Inspection

1. Etch .003 inches per surface
2. Coat piece with red visible penetrating dye (Met-L-Chek E150)
3. Set for at least 25 minutes
4. Remove dye with dye remover - emulsifier
5. Wipe completely dry
6. Spray with light coat of spirit developer
7. Check for red indications on white surface

2. In Process Inspection

All critical dimensions were inspected after every operation. Extensive tests were made after forging because of the metallurgical changes introduced by forging. These tests were:

a. Fluorescent penetrant inspection. The post emulsification method to expose any cracks developed during forging.

b. Macro examination of metal flow characteristics.

c. Micro examination of grain structure at head area.

3. Final Inspection

Upon completion of manufacture, the bolts were inspected for dimensional conformance to appropriate drawings particularly the threads for a Class 3A fit. Finally, the bolts were checked for cracks by the fluorescent penetrant method.

SECTION IV

PROBLEM AREAS AND PLANNED APPROACH FOR SOLVING PROBLEM AREAS

A. PROBLEM AREAS

The anticipated problems expected to be encountered will be threefold:

1. Selection of Beryllium Material for Suitable Fastener Application

   Although beryllium materials have been successfully fabricated into fasteners in the past, beryllium materials of different mill heats but with the same composition and process, historically exhibit different mechanical properties and forming characteristics. Therefore, process controls will have to be established to insure uniformity of fastener materials. The most promising material would be used to fabricate fasteners.

2. Development of a Beryllium Prestressed Fastener System

   The manufacture of beryllium threaded fasteners had previously consisted of only hexagon head and flush head shear type bolts. Semi-blind bolts with a hexagon recess at the thread point for driving purposes have never been manufactured. It is anticipated that the main problem in the fabrication of a beryllium point drive bolt will be the development of an optimum configuration for the hexagon recess. In addition, the development of a companion twist-off nut will go hand in hand with the recess design.

3. Development of a Beryllium Blind Fastener Assembly

   Because of the notch brittleness and poor ductility of beryllium material, the standard configurations and methods employed for the manufacturing of blind fasteners would not be feasible. Consequently, a reliable beryllium blind fastener employing components other than beryllium will have to be developed.

B. PLANNED APPROACH FOR SOLVING PROBLEM AREAS

1. Materials

   The contract calls for a minimum of three grades of beryllium material to be evaluated for prestressed fasteners and blind fasteners with minimum properties of:

Ultimate strength	-	75,000 psi
Shear strength	-	65,000 psi
Endurance limit	-	45,000 psi

Because the economics are favorable, it is proposed to procure four grades of beryllium material. The materials and suppliers would consist of:

a. PX 12 Extruded Rod - Beryllium Corporation

This material showed favorable properties in prior programs. It would be ordered in 485 inch quantities which would be sufficient for all work in Phases II and III.

b. QMV S-200C Extruded Rod - Brush Beryllium Company

This material would be supplied with a guaranteed 65,000 psi minimum shear strength. It would be the same type of material used successfully in a prior program.

c. Grade 3.0 - Beryllium Metals and Chemical Corporation

This material showed favorable properties when tested at SPS. The procurement of this material would consist of a 100 inch quantity which is now available on the shelf.

d. GB-2 - General Astrometals

General Astrometals offered a free sample of 48 inches of their material for inclusion in the test program. It will be accepted and tested with the other materials.

2. Development of a Prestressed Fastener System

The prestressed fastener assembly to be investigated will be that shown in Figures 3, 4, and 5. Other than the development of an optimum design for the hexagon recess and the establishment of twist-off torques for the aluminum nut, no major problems are expected to be encountered.

3. Development of Blind Fastener System

a. Design Alternatives

The technical proposal outlined several configurations of blind fasteners that were to be considered in this program. Common to blind fasteners in general are two basic methods of operation. First, a portion of the fastener will expand or deform radially in order to form some type of head on the blind side of the structure. Secondly, a portion of the fastener will break off when the required seating load is reached. This nature of installation presents several disadvantages when considering beryllium as a blind fastener material. Basically, poor ductility precludes the use of beryllium as the deformable member. Cost of the beryllium, combined with low ductility, reduces the advisability of using the standard "breaking off" method of installation for a beryllium core bolt. Therefore, the necessity arises of using other materials in conjunction with beryllium for the blind fastener. Since a primary objective in this program is to effect a weight reduction, low weight materials which have reasonable strength and ductility must be considered. Aluminum seems to possess these qualities and therefore will be considered initially. Other materials such as stainless steel and "Lockalloy" will be considered for possible elevated temperature work. This portion of the program will be devoted to an aluminum-beryllium blind fastener for low temperature usage.

b. Design Choice

Aluminum in its strongest condition does not possess maximum ductility. Yet in the blind fastener there is need for both ductility and high strength. High strength is required in the shear plane and in the deformed area there is need for maximum ductility. A logical continuation of this reasoning leads to the conclusion that the best possible blind fastener system would consist of a three-piece assembly. The deformable portion will have maximum ductility whereas the sleeve can be made with the highest strength. Figures 6 and 7 illustrate several representative blind fasteners. Based on the preceding discussion and the following criteria, it can be seen that the configuration shown in Figure 7 is the most logical choice.

Criteria:

(1) Light weight
(2) High strength
(3) Maximum temperature usage 250°F
(4) No part of the beryllium fastener should be broken off -- due to high material cost of beryllium.

Criterion #4 would, at first thought, rule out the configuration described in Figure 6. However, in this configuration it is possible to change to a point drive with an internal hex recess as shown in Figure 8, thus eliminating the necessity of breaking off the end of the beryllium bolt. Criterion #2 can be satisfied by choosing 7075 T6 aluminum for the sleeve material. The question remaining is what material should be chosen for the collar?

The collar is basic to the operation of the blind fastener that is described in Figure 8. There are several questions that should be answered pertinent to the collar.

(1) Can the collar be expanded?
(2) What is the collar column strength?
(3) What is the proper design of collar and sleeve lead angles?

Candidate materials of 2024-T4, 2014-T4, and 7075-T6 aluminum would be evaluated to answer these questions.

SECTION V

PROGRAM SCHEDULE

The schedule for the remainder of the program will be as shown in Figure 9.

PROJECTED PROGRAM SCHEDULE

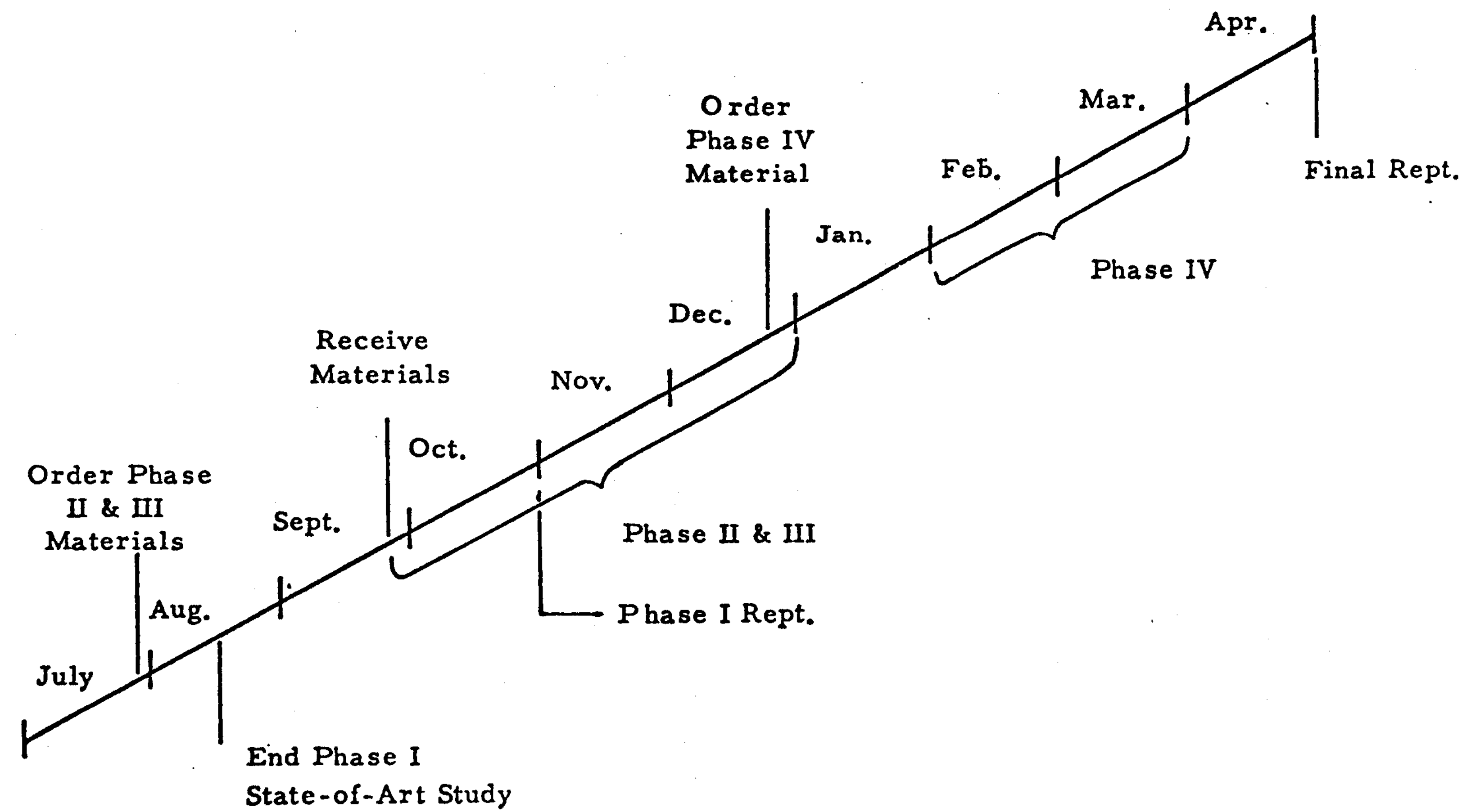


Figure 9

SECTION VI

REFERENCES

1. Edward F. Gowen, Jr. Beryllium Fasteners, AMC Technical Report 60-7-807, August 1960

APPENDIX I

TABLES

TABLE I

MECHANICAL PROPERTIES OF LOCKALLOY EXTRUSION ON DATA SUPPLIED BY BERYLLIUM CORPORATION

Reduction Ratio	Condition	Ult. Strength KSI	Yield KSI	Elongation % in 1"
6:1	1100°F - 12 hrs.	42.0	27.0	8.0
40:1	As Extruded	75.0	73.0	3.0
40:1	1100°F - 24 hrs.	61.6	48.0	10.0
35:1	1100°F - 24 hrs.	46.8	39.1	2.5
34:1	As Extruded	66.5	58.0	12.0
34:1	1100°F - 12 hrs.	57.0	41.0	18.0
45:1	1100°F - 25 hrs.	62.5	44.8	13.5
13:1	1100°F - 24 hrs.	57.8	39.4	15.5

TABLE II

MECHANICAL PROPERTIES OF EXTRUDED 3/8 IN. DIAMETER ROD

Data From Beryllium Corporation Contract AF33(657)-11271

Extrusion Number	Identity	U. T. S. (PSI)	Y. S. (PSI)	Elongation %
PX-3-339-79	Cast (2A)	36,600	30,500	4.15
PX-3-339-79	Cast (2A)	48,400	32,100	1.67
PX-3-338-80	Cast (2A)	43,800	32,400	1.26
PX-3-338-80	Cast (2A)	43,200	33,400	1.12
PX-3AF1-82	Cast (2A)	48,100	32,100	1.82
PX-3AF1-82	Cast (2A)	45,000	31,100	1.33
PX-3-2491-76	Low Oxide (2B)	94,700	45,900	14.51
PX-3-2491-76	Low Oxide (2B)	95,100	46,400	14.08
PX-3-861-48	Low Oxide (2B)	88,600	42,300	14.57
PX-3-861-48	Low Oxide (2B)	85,300	43,000	8.21
PX-3-861-48	Low Oxide (2B)	91,800	44,300	13.57
PX-3-2515-77	Select Standard (2C)	102,000	50,400	13.70
PX-3-2515-77	Select Standard (2C)	102,400	51,500	11.90
PX-3-PECH-96	Pechiney SR (2D)	96,800	51,600	10.26
PX-3-PECH-97	Pechiney SR (2D)	88,200	50,800	5.19
PX-3-PECH-97	Pechiney SR (2D)	98,300	51,800	12.91

TABLE III

COMPARISON OF ACTUAL MECHANICAL PROPERTIES OF BERYLLIUM BOLTS TO STEEL AND TITANIUM BOLTS OF NAS 464 CONFIGURATION

Berylco Beryllium Bolts

	Beryllium	Titanium	Steel
Bolt Tensile - PSI	78,000	172,000	200,000
Bolt Yield - PSI	46,400	141,000	180,000
Bolt Shear - PSI	72,000	108,000	116,000
Specimen Tensile - PSI	110,000	153,000	178,000
Specimen Yield - PSI	59,000	125,000	156,000
Specimen Elongation %	6.5	16	17
Specimen R of A %	10.0	40	52
Fatigue @ 83,000 PSI - cycles	—	115,000	22,000
Endurance Limit - PSI	45,000	60,000	20,000

Brush Beryllium Bolts

	Beryllium	Titanium	Steel
Bolt Tensile - PSI	73,800	172,000	200,000
Bolt Yield - PSI	37,300	141,000	180,000
Bolt Shear - PSI	60,800	108,000	116,000
Specimen Tensile - PSI	86,000	153,000	178,000
Specimen Yield - PSI	41,000	125,000	156,000
Specimen Elongation %	3.0	16	17
Specimen R of A %	5.6	40	52
Fatigue @ 83,000 PSI- cycles	—	115,000	22,000
Endurance Limit - PSI	50,000	60,000	20,000

TABLE IV

COMPARISON OF MECHANICAL PROPERTIES ON STRENGTH-TO-WEIGHT RATIO OF BERYLLIUM BOLTS TO STEEL AND TITANIUM BOLTS OF NAS 464 CONFIGURATION

Results in stress/density units

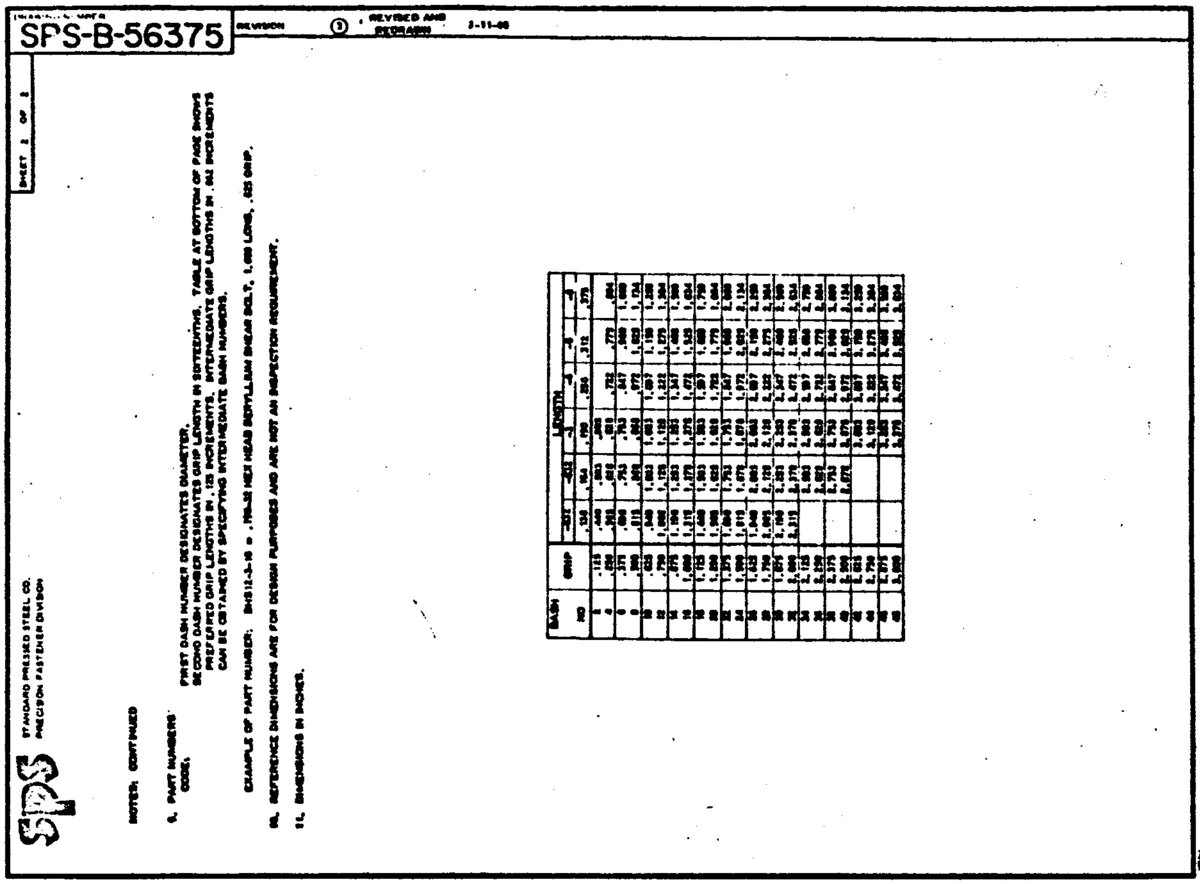
Beryllium Density	.066 pounds per cubic inch
Titanium Density	.16 pounds per cubic inch
Steel Density	.28 pounds per cubic inch

Beryllium Tensile Strength	78,000 psi
Titanium Tensile Strength	172,000 psi
Steel Tensile Strength	200,000 psi

	Berylco Beryllium Bolts	Brush Beryllium Bolts	4Al-4Mn Titanium Bolts	Steel Bolts
Bolt Tensile Ratio	1,182,000	1,118,000	1,074,000	715,000
Specimen Tensile Ratio	1,666,000	1,348,000	956,000	635,000
Bolt Shear Ratio	1,100,000	922,000	675,000	414,000
Endurance Limit Ratio	682,000	834,000	375,000	71,500

APPENDIX II

ILLUSTRATIONS



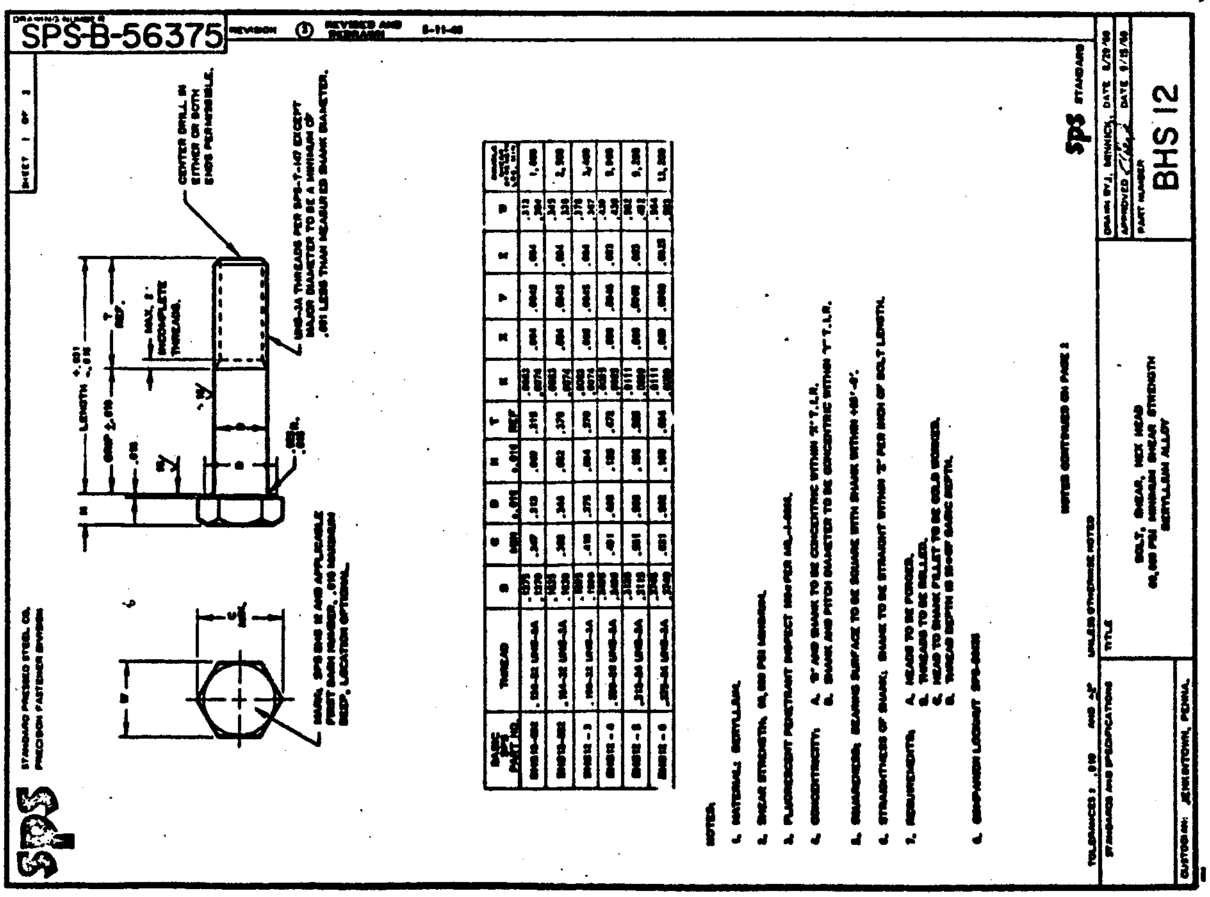
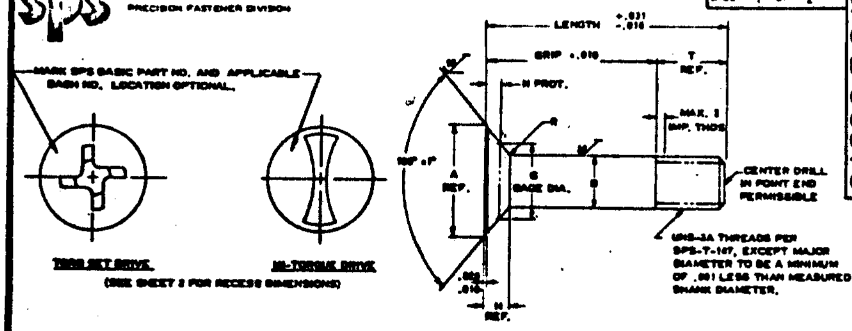


Figure 1

SPS STANDARD PRESSED STEEL CO.
PRECISION FASTENER DIVISION

DRAWING NUMBER SPS-B-56376 | REVISION ④ REVISED AND REDRAWN 3-12-65 | SHEET 1 OF 2



BASIC PART NO. TORQ SET	BASIC PART NO. HI TORQUE	THREAD	A REF	B	G REF	H REF	K	N	R	T REF	V	Z	SINGLE SHEAR STRENGTH LBS. MIN
BFT12-632	BFH12-632	.138-32 UNJC-3A	.279 .269	.1375 .1370	.1065	.087	.0083 .0074	.0332 .0302	.020 .010	.315	.0045	.004	1,800
BFT12-832	BFH12-832	.164-32 UNJC-3A	.338 .327	.1635 .1630	.2400	.066	.0081 .0074	.0404 .0372	.020 .010	.370	.0045	.004	2,500
BFT12-3	BFH12-3	.190-32 UNJF-3A	.387 .378	.1895 .1890	.3270	.080	.0083 .0074	.0246 .0205	.020 .010	.370	.0045	.004	3,400
BFT12-4	BFH12-4	.250-28 UNJF-3A	.510 .498	.2495 .2490	.4330	.106	.0095 .0085	.0321 .0274	.020 .010	.472	.0045	.003	5,900
BFT12-5	BFH12-5	.312-24 UNJF-3A	.636 .622	.3120 .3115	.5430	.133	.0111 .0099	.0363 .0329	.023 .010	.525	.006	.003	9,200
BFT12-6	BFH12-6	.375-24 UNJF-3A	.760 .746	.3745 .3740	.6540	.160	.0111 .0099	.0444 .0384	.030 .015	.634	.006	.0025	13,300

NOTES:

1. MATERIAL: BERYLLIUM.
2. SHEAR STRENGTH: 60,000 PSI MINIMUM.
3. FLUORESCENT PENETRANT INSPECT 100%. PER MIL-I-6866.
4. CONCENTRICITY:
   - A. SHANK AND THREAD P.D. TO BE CONCENTRIC WITHIN "V" T.I.R.
   - B. CONICAL SURFACE OF HEAD TO BE CONCENTRIC WITH SHANK WITHIN .005 T.I.R.
   - C. RECESS TO BE CONCENTRIC WITH SHANK WITHIN .016 THRU , AND WITHIN .024 ABOVE
5. STRAIGHTNESS OF SHANK:
   SHANK TO BE STRAIGHT WITHIN "Z" T.I.R. PER INCH OF LENGTH.
6. REQUIREMENTS:
   - A. HEADS TO BE FORGED.
   - B. THREADS TO BE ROLLED.
   - C. HEAD TO SHANK FILLET TO BE COLD WORKED.
   - D. THREAD DEPTH IS 75% OF BASIC DEPTH.
7. COMPANION LOCKNUT SPS-36426.
8. PART NUMBERS:
   CODE:
   FIRST DASH NUMBER DESIGNATES DIAMETER.
   SECOND DASH NUMBER DESIGNATES GRIP LENGTH IN SIXTEENTHS.
   TABLE ON SHEET 2 SHOWS PREFERRED GRIP LENGTHS IN .125 INCREMENTS.
   INTERMEDIATE GRIP LENGTHS IN .062 INCREMENTS CAN BE OBTAINED BY SPECIFYING INTERMEDIATE DASH NUMBERS.
9. EXAMPLE OF PART NUMBER:
   BFT12-5-16 = .312-24 FLUSH HEAD BERYLLIUM SHEAR BOLT, TORQ SET RECESS, 1.525 LONG, 1.000 GRIP.
   BFH12-5-16 = .312-24 FLUSH HEAD BERYLLIUM SHEAR BOLT, HI-TORQUE RECESS, 1.525 LONG, 1.000 GRIP.
10. REFERENCE DIMENSIONS ARE FOR DESIGN PURPOSES AND ARE NOT AN INSPECTION REQUIREMENT.
11. DIMENSIONS IN INCHES.

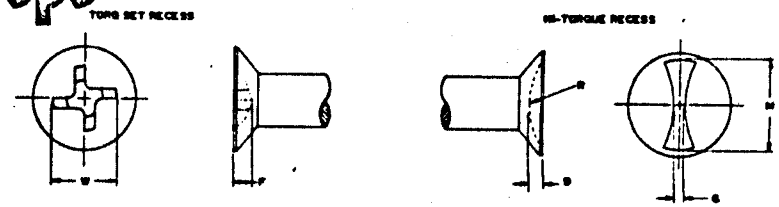
SPS STANDARD

TOLERANCES: ±.010 AND ±2° UNLESS OTHERWISE NOTED

STANDARDS AND SPECIFICATIONS	TITLE	
CUSTODIAN: JENKINTOWN, PENNA.	BOLT, SHEAR, FLUSH HEAD TORQ SET RECESS - HI TORQUE RECESS 60,000 PSI MINIMUM SHEAR STRENGTH BERYLLIUM ALLOY	DRAWN BY J. MINNICK DATE 6-30-60; APPROVED DATE 9-15-60; PART NUMBER BFT12 BFH12

SPS STANDARD PRESSED STEEL CO.
PRECISION FASTENER DIVISION

DRAWING NUMBER SPS-B-56376 | REVISION ④ REVISED AND REDRAWN 3-12-65 | SHEET 2 OF 2



BASIC PART NO.	W	F
BFT12-632	.182 .172	.064 .054
BFT12-832	.215 .205	.070 .060
BFT12-3	.244 .234	.090 .080
BFT12-4	.325 .315	.110 .100
BFT12-5	.357 .347	.122 .112
BFT12-6	.427 .417	.140 .125

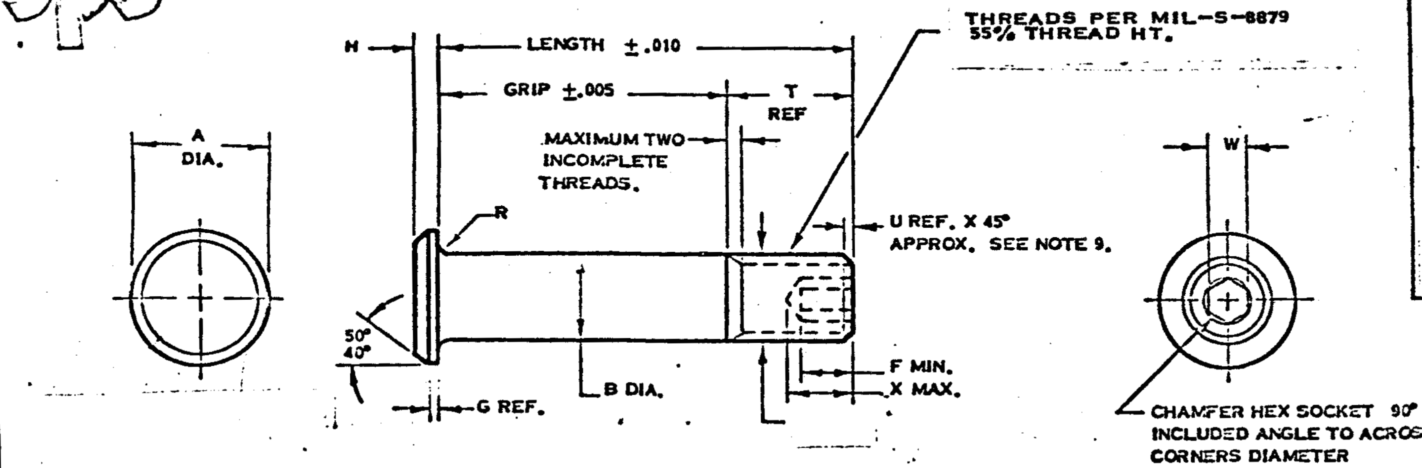
BASIC PART NO.	E	D	M REF	R
BFH12-632	.064 .060	.043 .039	.225	.170 .160
BFH12-832	.064 .060	.053 .050	.265	.192 .182
BFH12-3	.064 .060	.045 .042	.305	.286 .276
BFH12-4	.078 .074	.054 .051	.422	.442 .432
BFH12-5	.084 .080	.064 .061	.496	.505 .495
BFH12-6	.100 .096	.088 .084	.630	.630 .620

DASH NO.	GRIP	LENGTH -632 .138	LENGTH -832 .164	LENGTH -3 .190	LENGTH -4 .250	LENGTH -5 .312	LENGTH -6 .375
2	.125	.440	.503	.503			
4	.250	.565	.628	.628	.722	.775	.884
6	.375	.690	.753	.753	.847	.900	1.009
8	.500	.815	.878	.878	.972	1.025	1.134
10	.625	.940	1.003	1.003	1.097	1.150	1.259
12	.750	1.065	1.128	1.128	1.222	1.275	1.384
14	.875	1.190	1.253	1.253	1.347	1.400	1.509
16	1.000	1.315	1.378	1.378	1.472	1.525	1.634
18	1.125	1.440	1.503	1.503	1.597	1.650	1.759
20	1.250	1.565	1.628	1.628	1.722	1.775	1.884
22	1.375	1.690	1.753	1.753	1.847	1.900	2.009
24	1.500	1.815	1.878	1.878	1.972	2.025	2.134
26	1.625	1.940	2.003	2.003	2.097	2.150	2.259
28	1.750	2.065	2.128	2.128	2.222	2.275	2.384
30	1.875	2.190	2.253	2.253	2.347	2.400	2.509
32	2.000	2.315	2.378	2.378	2.472	2.525	2.634
34	2.125		2.503	2.503	2.597	2.650	2.759
36	2.250		2.628	2.628	2.722	2.775	2.884
38	2.375		2.753	2.753	2.847	2.900	3.009
40	2.500		2.878	2.878	2.972	3.025	3.134
42	2.625			3.003	3.097	3.150	3.259
44	2.750			3.128	3.222	3.275	3.384
46	2.875			3.253	3.347	3.400	3.509
48	3.000			3.378	3.472	3.525	3.634

Figure 2

STANDARD PRESSED STEEL CO
PRECISION FASTENER DIVISION

PD 300.61085



REVISION (2) REVISED AND REDRAWN 12-16-64
(3) 3-27-65

BASIC PART NO.	THREAD MOD.	A DIA.	B DIA.	D DIA.	F MIN.	G REF.	H	R RAD.	T REF.	U REF.	* W	* X MAX.	Y	Z
PDP 16-6	.190-32 UNF-3A	.315 .305	.1895 .1885		.125	.060	.110 .100	.025 .015	.355	.040	.0645 .0635	.156	.0045	.0040
PDP 16-8	.250-28 UNF-3A	.412 .397	.2495 .2485		.156	.070	.138 .128	.025 .015	.425	.040	.0801 .0781	.187	.0045	.0030
PDP 16-10	.312-24 UNF-3A	.505 .475	.3120 .3110		.187	.080	.156 .146	.030 .020	.530	.050	.0962 .0937	.250	.0045	.0030

NOTES:

1. MATERIAL BERYLLIUM
2. HEAT TREAT:
3. FINISH ETCHED TO FINISH DIMENSIONS
4. CONCENTRICITY: "A" AND "B" DIAMETERS WITHIN .010 T.I.R., HEXAGON SOCKET AND THREAD P.D. WITHIN .010 T.I.R. THREAD P.D. AND "B" DIAMETER WITHIN "Y" VALUES T.I.R.
5. SHANK MUST BE STRAIGHT WITHIN "Z" VALUES T.I.R. PER INCH OF BOLT LENGTH.
6. PART NUMBER: FIRST DASH NUMBER DESIGNATES DIAMETER IN 1/32NDS. SECOND DASH NUMBER DESIGNATES GRIP IN 1/32NDS. EXAMPLE: PDP 16-8-16 = .250-28 PROTRUDING HEAD BOLT, .500 GRIP, .925 LONG.
7. SURFACE ROUGHNESS: (RHR MAXIMUM PER ASA B46.1) HEAD TO SHANK FILLET, THREAD ROOT, THREAD SIDES AND THREAD RUNOUT 16; SHANK AND BEARING SURFACE OF HEAD 40; OTHER SURFACES 125.
8. REFERENCE DIMENSIONS ARE FOR DESIGN PURPOSES ONLY AND ARE NOT AN INSPECTION REQUIREMENT.
9. CHAMFER "U" PLUS INCOMPLETE THREADS NOT TO EXCEED TWO PITCHES.
10. DIMENSIONS ARE AFTER PLATING.
11. * GAGING OF HEXAGON SOCKET PER ASA B18.3 1961 APPENDIX 1, EXCEPT ALL "E" (NOT GO GAGE WIDTH) DIMENSIONS TO BE INCREASED .001.
12. *

SPS STANDARD

TOLERANCES: ±.010 AND ±2° UNLESS OTHERWISE NOTED

* DENOTES LATEST CHANGE.

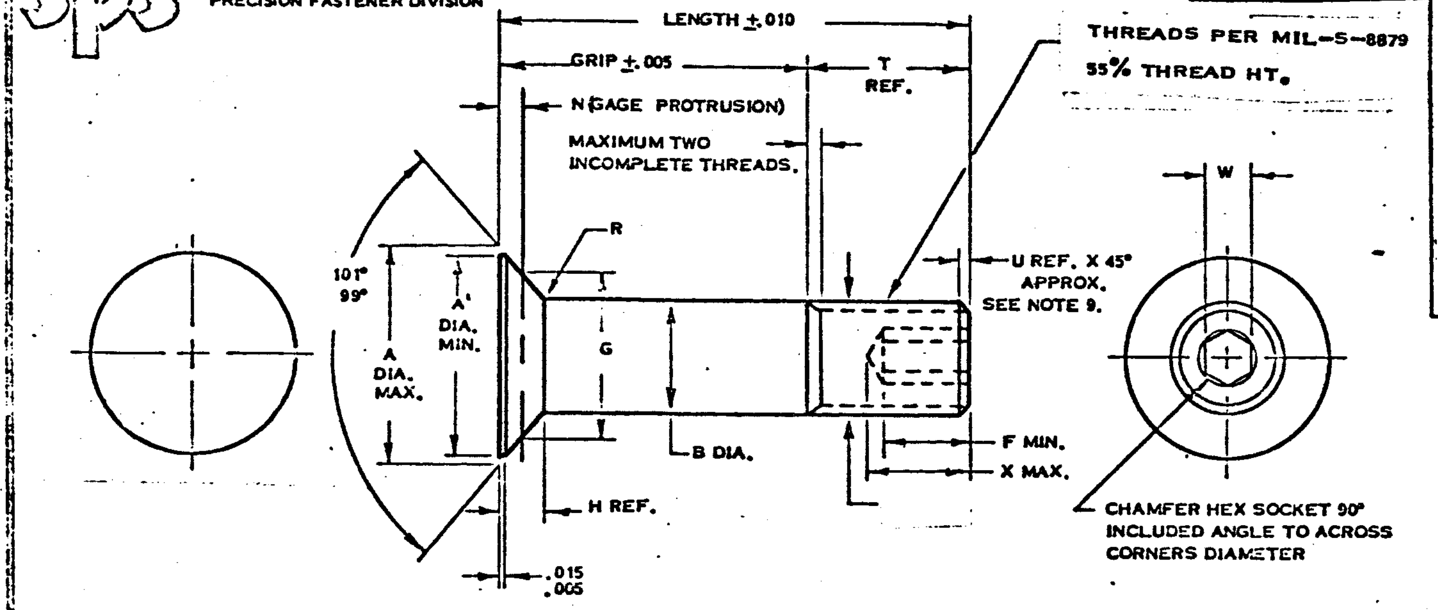
STANDARDS AND SPECIFICATIONS	TITLE	PART NUMBER
	BOLT, SHEAR, POINT DRIVE - PROTRUDING HEAD BERYLLIUM MATERIAL	PDP 16
CUSTODIAN: JENKINTOWN		

Figure 3

STANDARD PRESSED STEEL CO.
PRECISION FASTENER DIVISION

PD 300.61084

REVISION



BASIC PART NO.	THREAD MOD.	A MAX. 1/	A' MIN. 2/	B DIA.	D DIA.	F MIN.	G GAGE DIA.	H REF.	N	R RAD.	T REF.	U REF.	W	X MAX.	Y	Z
PTF16-3	.190-32 UNF-3A	.302	.257	.1895 .1890	.1840 .1810	.125	.2210 .2208	.046	.0333 .0305	.030 .020	.325	.040	.0645 .0635	.156	.0045	.0040
PTF16-4	.250-28 UNF-3A	.395	.349	.2495 .2490	.2440 .2410	.156	.2832 .2830	.060	.0416 .0430	.030 .020	.395	.040	.0801 .0781	.187	.0045	.0030
PTF16-5	.312-24 UNF-3A	.474	.428	.3120 .3115	.3060 .3020	.187	.3422 .3420	.067	.0544 .0513	.040 .030	.500	.050	.0962 .0937	.250	.0045	.0030

1/ TO THEORETICAL SHARP CORNER   2/ ABSOLUTE MINIMUM WITH FLAT.

NOTES:

1. MATERIAL BERYLLIUM
2. HEAT TREAT
3. FINISH PLAIN ETCHED TO FINISH DIMENSIONS
4. CONCENTRICITY: CONICAL SURFACE OF HEAD TO "B" DIAMETER WITHIN .005 T.I.R.
   THREAD P.D. AND "B" DIAMETER WITHIN "Y" VALUES T.I.R.
   HEXAGON SOCKET AND THREAD P.D. WITHIN .010 T.I.R.
5. SHANK MUST BE STRAIGHT WITHIN "Z" VALUES T.I.R. PER INCH OF BOLT LENGTH.
6. PART NUMBER: FIRST DASH NUMBER DESIGNATES DIAMETER.
   SECOND DASH NUMBER DESIGNATES GRIP LENGTH IN 1/16 THS.

   EXAMPLE: PTF16-5-10= .312-24 DIAMETER BOLT, .625 GRIP, 1.125 LONG.
7. SURFACE ROUGHNESS (RHR MAXIMUM PER ASA B46.1) HEAD TO SHANK FILLET, THREAD ROOT, THREAD SIDES, AND THREAD RUNOUT 16; SHANK AND HEAD BEARING SURFACE 40, OTHER SURFACES 125.
8. REFERENCE DIMENSIONS ARE FOR DESIGN PURPOSES AND ARE NOT AN INSPECTION REQUIREMENT.
9. CHAMFER "U" PLUS INCOMPLETE THREADS NOT TO EXCEED TWO PITCHES.
10. GAGING OF HEXAGON SOCKET PER ASA B18.3 1961 APPENDIX I, EXCEPT ALL "E" (NOT GO GAGE WIDTH) DIMENSIONS TO BE INCREASED .001.
11.

SPS STANDARD

TOLERANCES ± .010 AND ±2° UNLESS OTHERWISE NOTED

STANDARDS AND SPECIFICATIONS	TITLE	
	BOLT, SHEAR, POINT DRIVE - 100° FLUSH HEAD BERYLLIUM MATERIAL 1/16 GRIP VARIATION APPLICATIONS	PART NUMBER PTF 16
CUSTODIAN: JENKINTOWN, PA.		

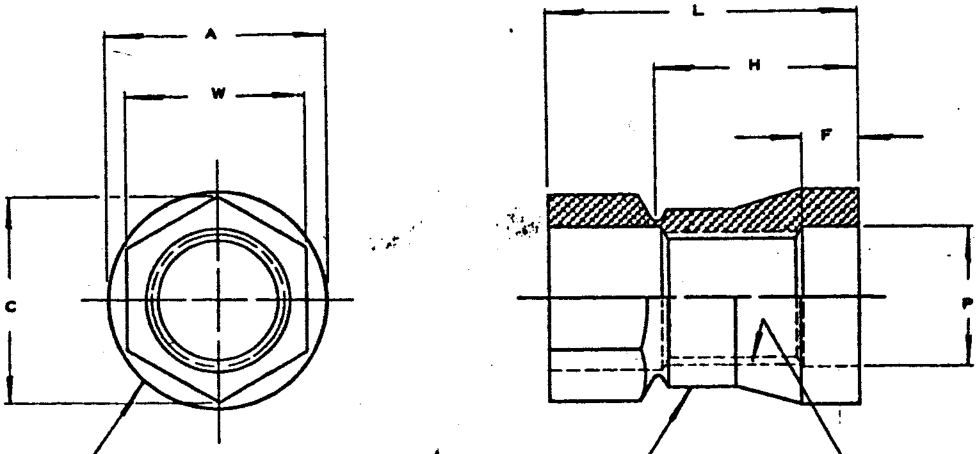
Figure 4

STANDARD PRESSED STEEL CO.
PRECISION FASTENER DIVISION

SHEET 1 OF 1

SPS-N-63260

REVISION A — REVISED AND REDRAWN 12-28-64



PART NUMBER	(1) THREAD	A MAX.	C MIN.	F ±.010	H REF.	L ±.010	P ±.005	W MAX.	W MIN.	(2) X	TORQUE OFF IN. LBS.	AXIAL TENSILE STRENGTH LBS. MIN.	(3) WEIGHT MAXIMUM LBS./100
TN 12-5	.164-32 UNC-3B	.295	.347	.132	.310	.467	.184	.313	.305	.005	15-25	1,220	.12
TN 12-6	.190-32 UNF-3B	.310	.347	.132	.320	.477	.210	.313	.305	.005	25-35	1,410	.12
TN 12-8	.250-28 UNF-3B	.415	.383	.138	.380	.572	.270	.345	.336	.005	65-80	2,560	.25
TN 12-10	.312-24 UNF-3B	.520	.491	.143	.470	.692	.334	.439	.430	.005	150-180	4,100	.52
TN 12-12	.375-24 UNF-3B	.630	.561	.143	.510	.764	.396	.502	.492	.005	200-240	6,200	.78
TN 12-14	.437-20 UNF-3B	.715	.631	.154	.600	.882	.460	.564	.553	.005	270-330	8,200	1.19
TN 12-16	.500-20 UNF-3B	.815	.775	.154	.650	.962	.522	.690	.679	.005	370-430	10,500	1.65

(1) THREADS: BEFORE LUBRICATION PER MIL-S-7742.
(2) BEARING SQUARENESS: BEARING SURFACE TO BE SQUARE WITH PITCH DIAMETER WITHIN "X" T.I.R.
(3) MAXIMUM WEIGHT REFERS TO PORTION OF NUT DEFINED BY DIMENSION "H" REFERENCE.

MATERIAL: 2024-T4 ALUMINUM ALLOY.
COATING: ANODIZE PER MIL-A-8625, TYPE II, DYE BLACK.
LUBRICANT: DRY FILM LUBRICANT APPROVED PER MIL-N-25027.
NON-DRY LUBRICANT: UNLESS OTHERWISE SPECIFIED, PARTS SHALL BE SUPPLIED WITH A NON DRY LUBRICANT (CETYL ALCOHOL) SOLUBLE IN THE CLEANER SPECIFIED IN MIL-S-7502.
LOCKING TORQUE: NUT TO PROVIDE PREVAILING TORQUE FOR ONE APPLICATION.
BREAK SHARP CORNERS.
DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE.
DIMENSIONS TO BE MET PRIOR TO LUBRICANT.
SURFACE TEXTURE: ASA-B46, UNLESS OTHERWISE SPECIFIED THE SURFACE TEXTURE SHALL NOT EXCEED 125 MICROINCHES.
DESIGN AND USAGE LIMITATIONS: THESE NUTS ARE DESIGNED TO BE USED WITH BOLTS AND SCREWS WITH A SHEAR STRENGTH OF 95 KSI. THE NUTS ARE TO BE USED ON CLASS 3A EXTERNAL THREADS WITHIN THE LIMITATIONS OF MS 33588.
PART NUMBER: SPS PART NUMBER CONSISTS OF "TN 12" PLUS APPLICABLE DASH NUMBER. ADD LETTER "X" TO "TN 12" FOR NO LUBRICANT. ADD LETTER "M" FOR MOLYBDENUM DISULFIDE DRY FILM LUBRICANT. NO LETTER DESIGNATES CETYL ALCOHOL LUBRICANT.

EXAMPLE: TN 12-8 = .250-28 UNF-3B TORQUE NUT WITH CETYL ALCOHOL LUBRICANT.
TN 12 X-8 = .250-28 UNF-3B TORQUE NUT WITH NO LUBRICANT.

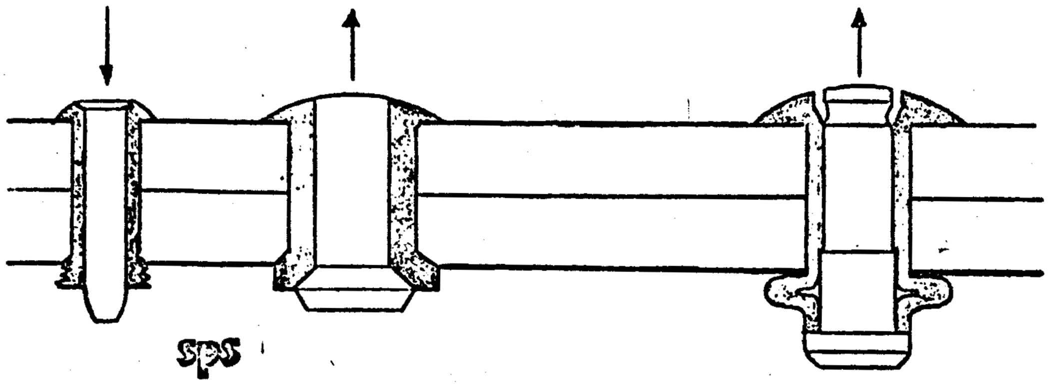
THIS STANDARD TAKES PRECEDENCE OVER DOCUMENTS REFERENCED HEREIN. REFERENCED DOCUMENTS SHALL BE OF THE ISSUE IN EFFECT ON DATE OF INVITATIONS FOR BID.

PATENT APPLIED FOR — SPS STANDARD

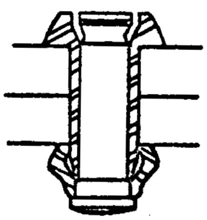
TOLERANCES ± ——— AND ——— UNLESS OTHERWISE NOTED

STANDARDS AND SPECIFICATIONS	TITLE	
	NUTS, SELF-LOCKING, TORQUE, 2024-T4 ALUMINUM, 250° F., FOR 3/32 GRIP VARIATION.	DRAWN BY W. N. DATE 10.21.63
		APPROVED DATE 10/21/63
JENKINTOWN, PA.		PART NUMBER TN 12

Figure 5



<u>Figure 6.</u> **Representative Blind Fasteners.**



<u>Figure 7.</u> **Huck Type Tau Blind Bolt.**

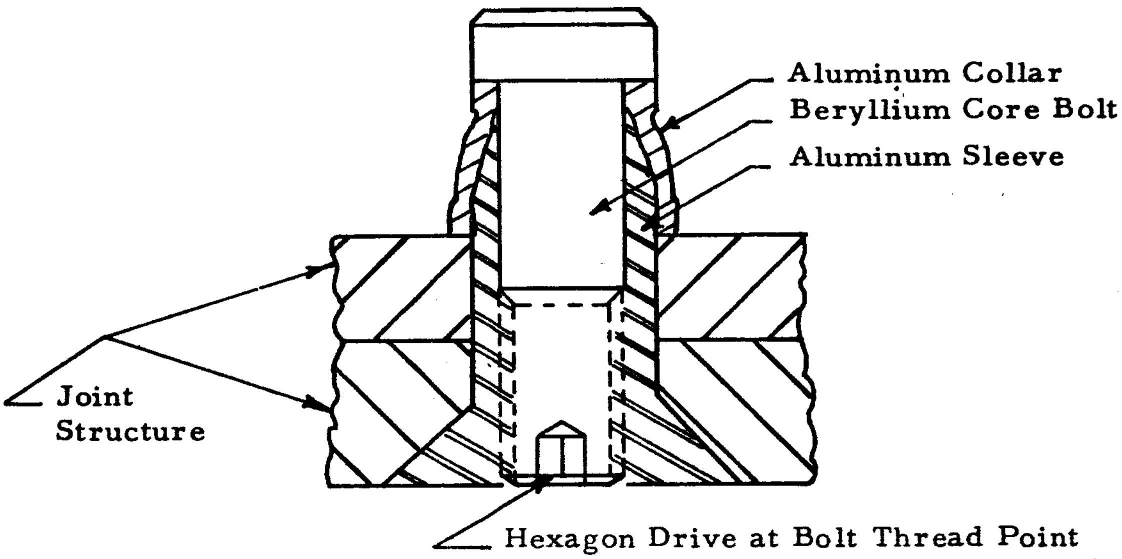


Figure 8. Proposed Blind Fastener System to be Evaluated

APPENDIX III

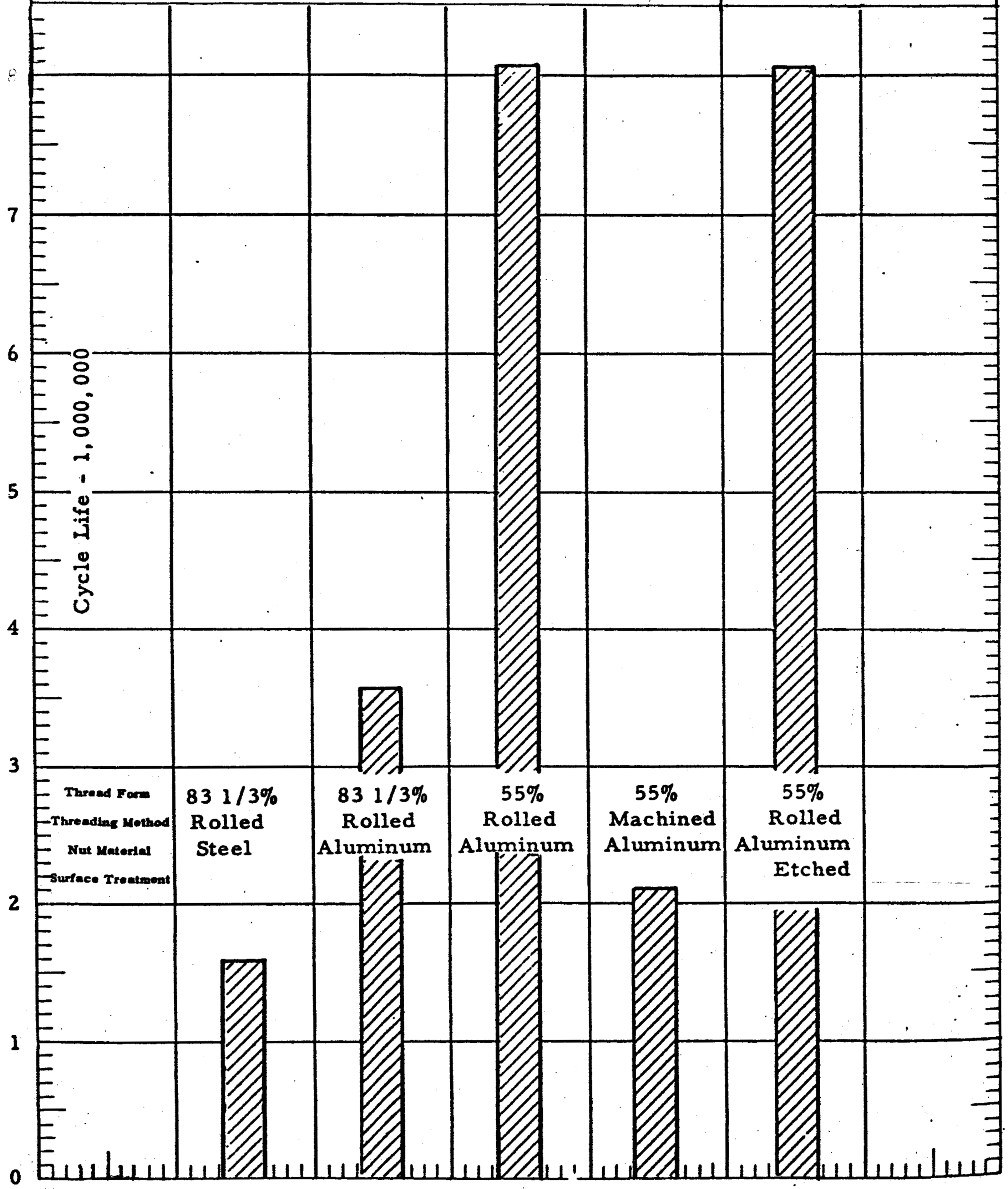
CHARTS

TENSION-TENSION FATIGUE STRENGTH

Tested 1/4-28 Bolts
Stress - 45,000 psi
Berylco Material
HPN Ground Extruded Bar
Heat Number PXB 43

SPS LABORATORIES

Chart No.: 1
Date: 3-2-60

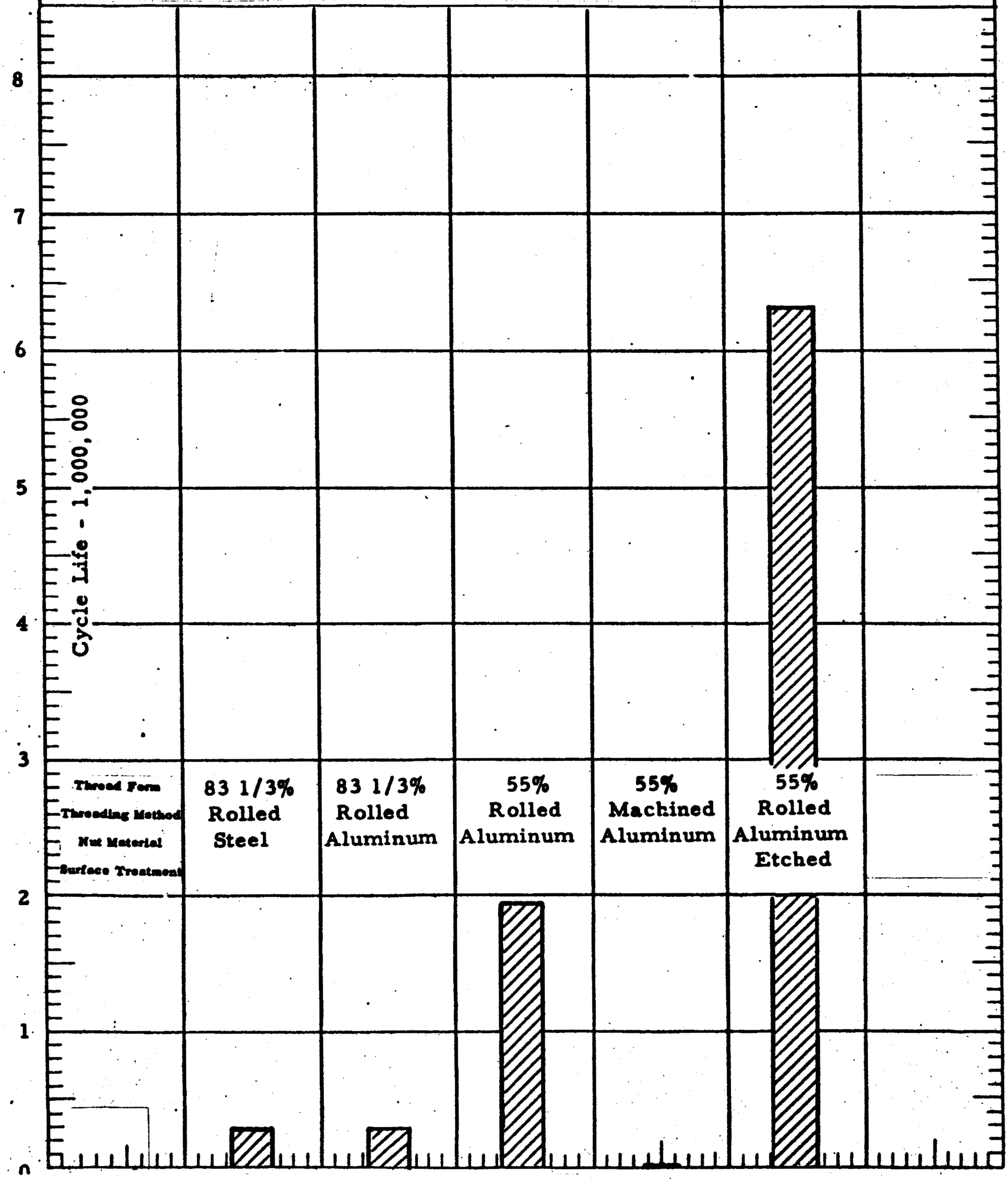


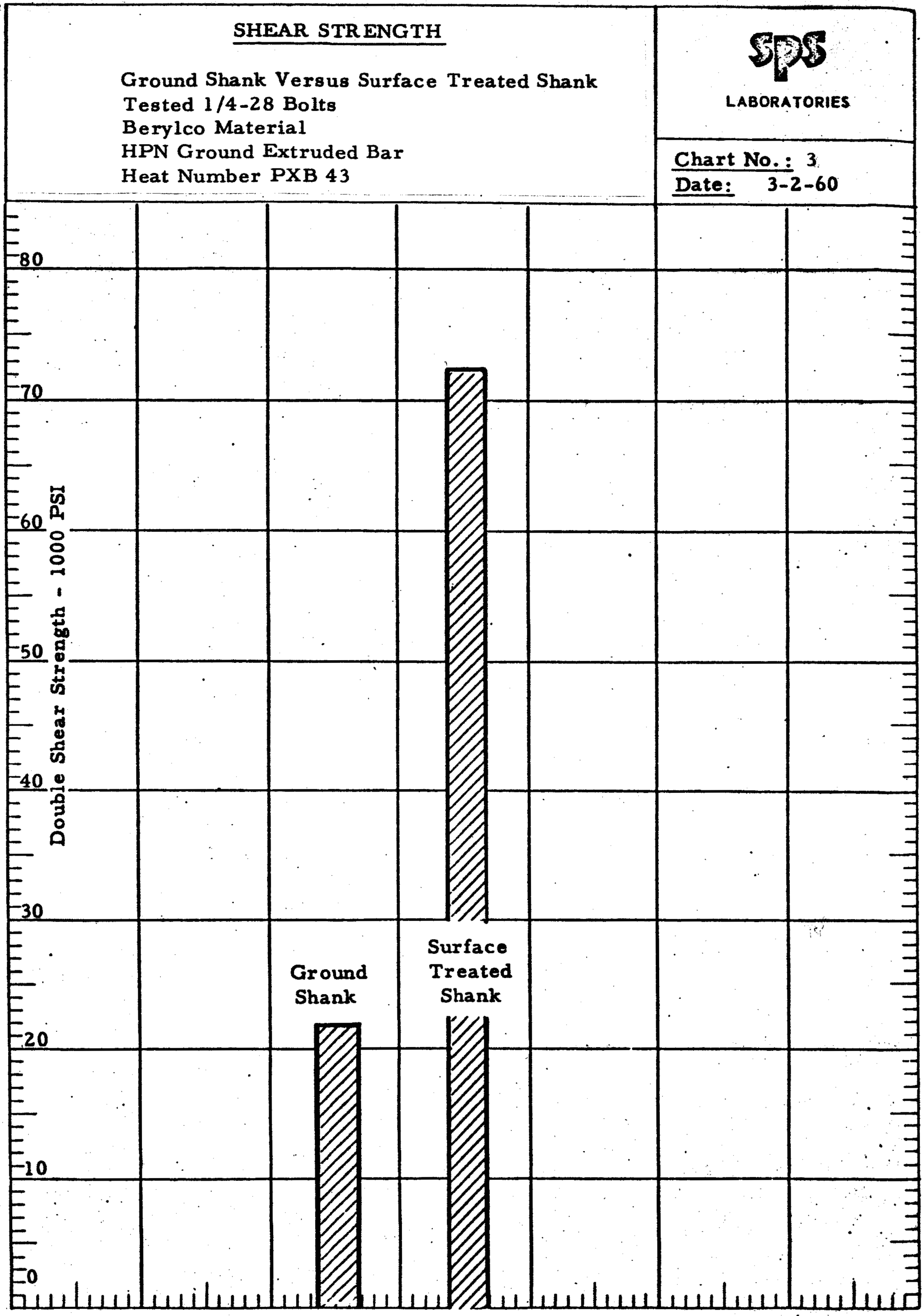
TENSION-TENSION FATIGUE STRENGTH

Tested 5/16-24 Bolts
Stress - 55,000 psi
Brush Material
QVM Warm Extruded Bar
Hot Pressed Block Number 23-11-5080

SPS LABORATORIES

Chart No.: 2
Date: 3-2-60



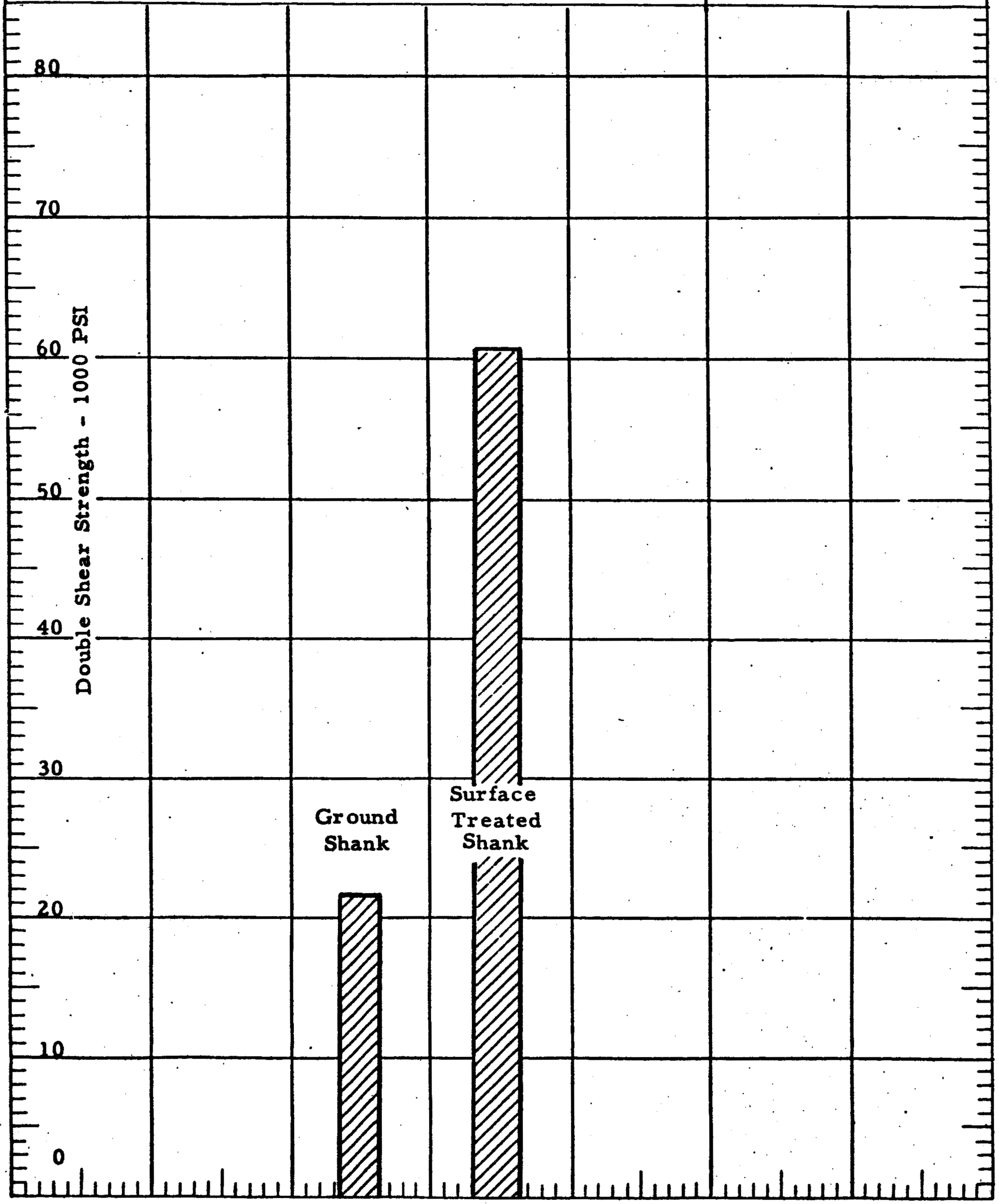

SHEAR STRENGTH
Ground Shank Versus Surface Treated Shank
Tested 1/4-28 Bolts
Berylco Material
HPN Ground Extruded Bar
Heat Number PXB 43
SPS
LABORATORIES
Chart No.: 3
Date: 3-2-60
Double Shear Strength - 1000 PSI
80
70
60
50
40
30
20
10
0
Ground
Shank
Surface
Treated
Shank

SHEAR STRENGTH

Ground Shank Versus Surface Treated Shank
Tested on 5/16-24 Bolts
Brush Material
QVM Warm Extruded Bar
Hot Pressed Block Number 23-11-5080

SPS LABORATORIES

Chart No.: 4
Date: 3-2-60

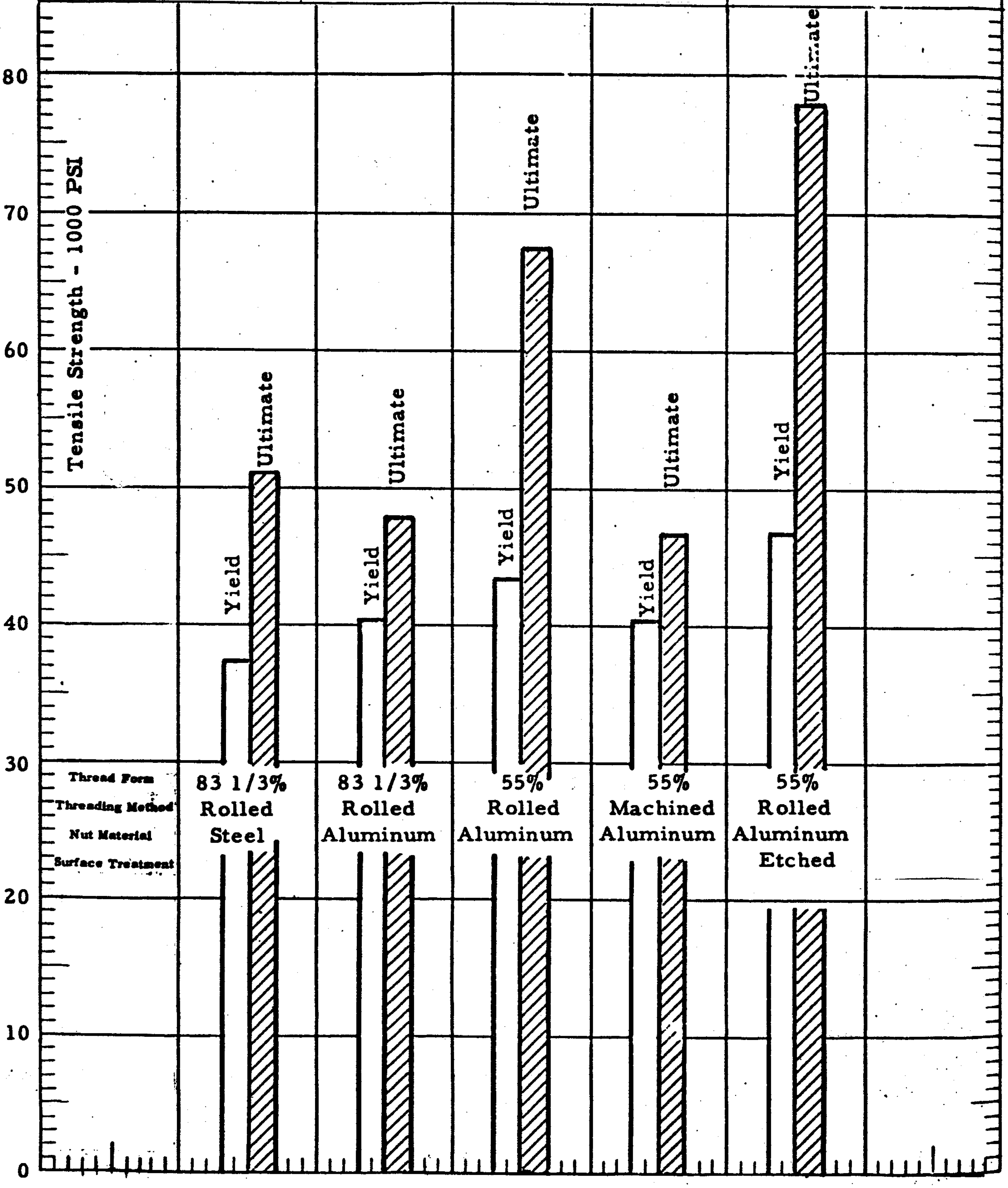


ULTIMATE TENSILE AND JOHNSON'S
2/3 APPROXIMATION YIELD STRENGTH

Tested 1/4-28 Bolts
(NAS 464-4-A14 Configuration)
Berylco Material
HPN Ground Extruded Bar
Heat Number PXB 43

SPS LABORATORIES

Chart No.: 5
Date: 3-2-60

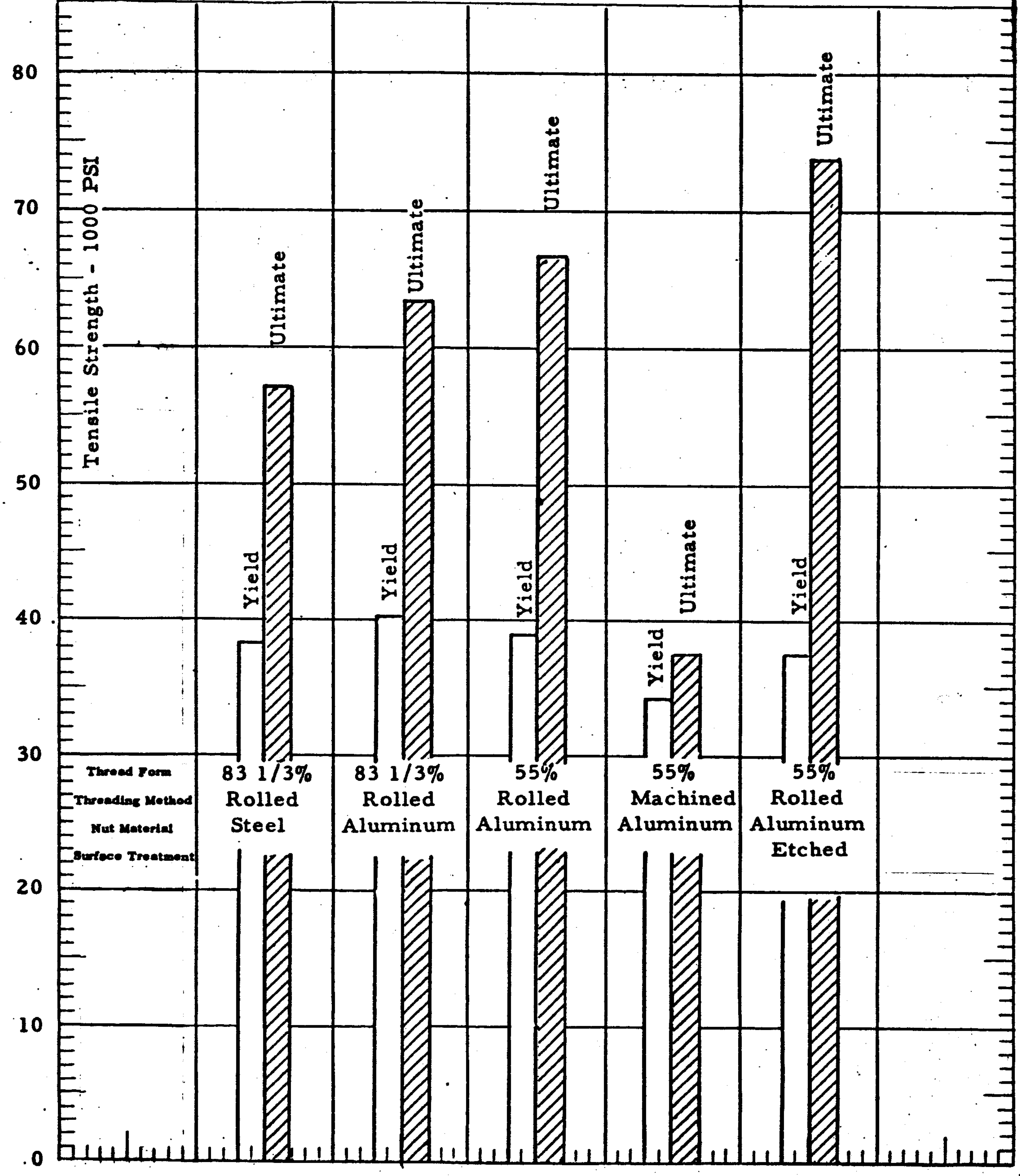


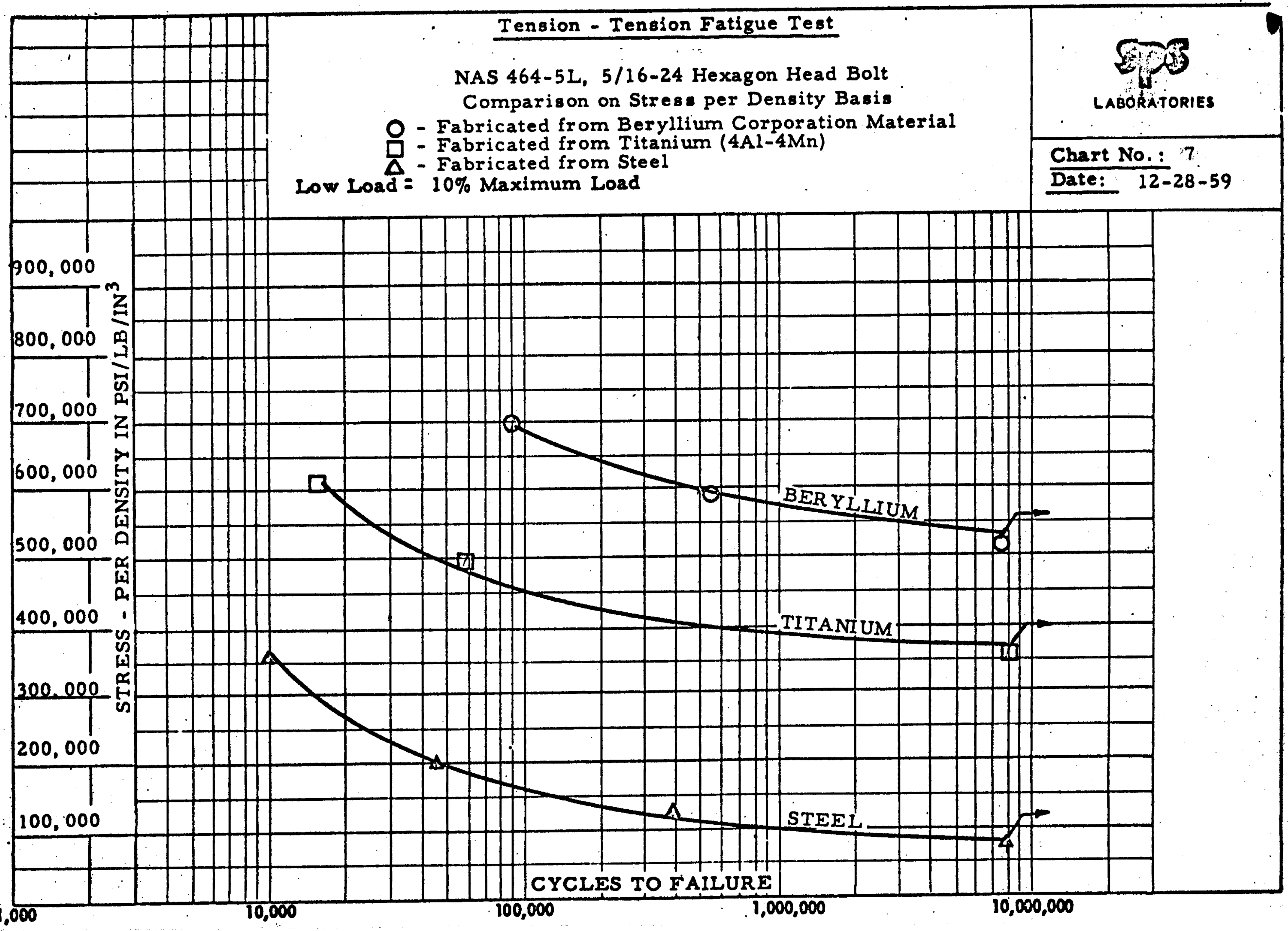
ULTIMATE TENSILE AND JOHNSON'S 2/3 APPROXIMATION YIELD STRENGTH

Tested 5/16-24 Bolts
(NAS 464-5L-A14 Configuration)
Brush Material
QVM Warm Extruded Bar
Hot Pressed Block Number 23-11-5080

SPS LABORATORIES

Chart No. 6.
Date: 3-2-60



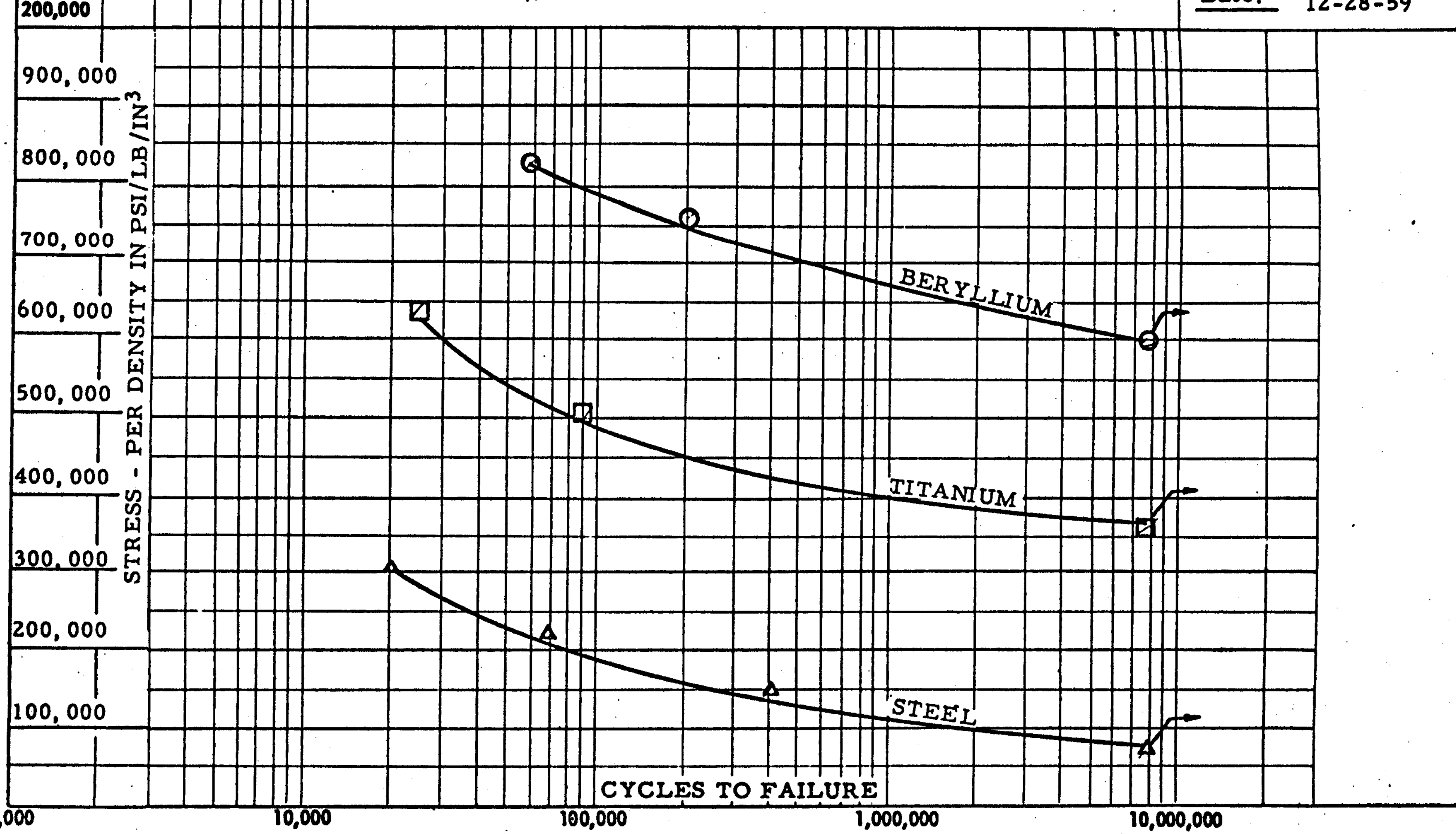

Tension - Tension Fatigue Test
NAS 464-5L, 5/16-24 Hexagon Head Bolt
Comparison on Stress per Density Basis
○ - Fabricated from Beryllium Corporation Material
□ - Fabricated from Titanium (4Al-4Mn)
△ - Fabricated from Steel
Low Load = 10% Maximum Load
LABORATORIES
Chart No.: 7
Date: 12-28-59
STRESS - PER DENSITY IN PSI/LB/IN³
900,000
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
BERYLLIUM
TITANIUM
STEEL
CYCLES TO FAILURE
1,000
10,000
100,000
1,000,000
10,000,000

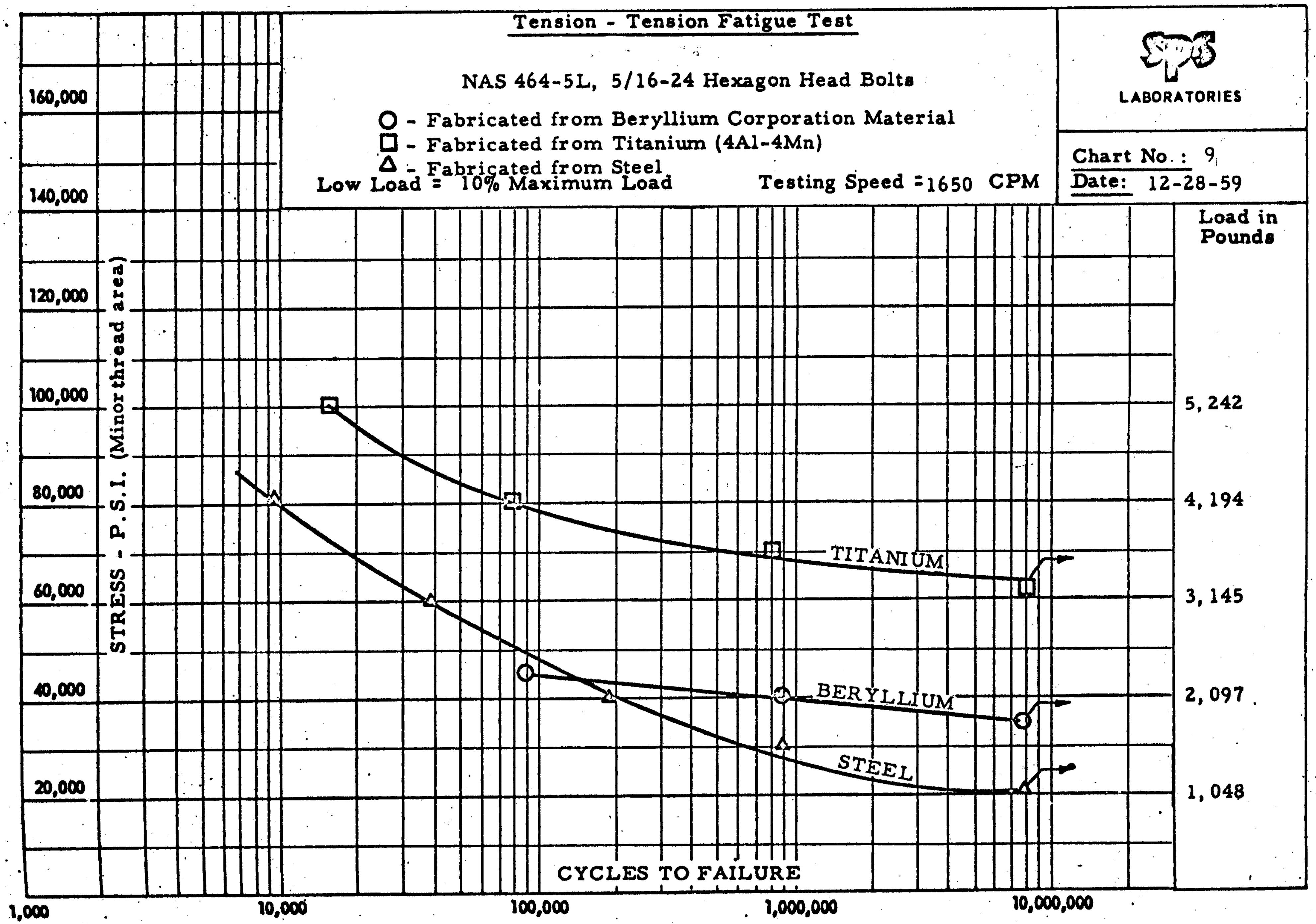
Tension - Tension Fatigue Test

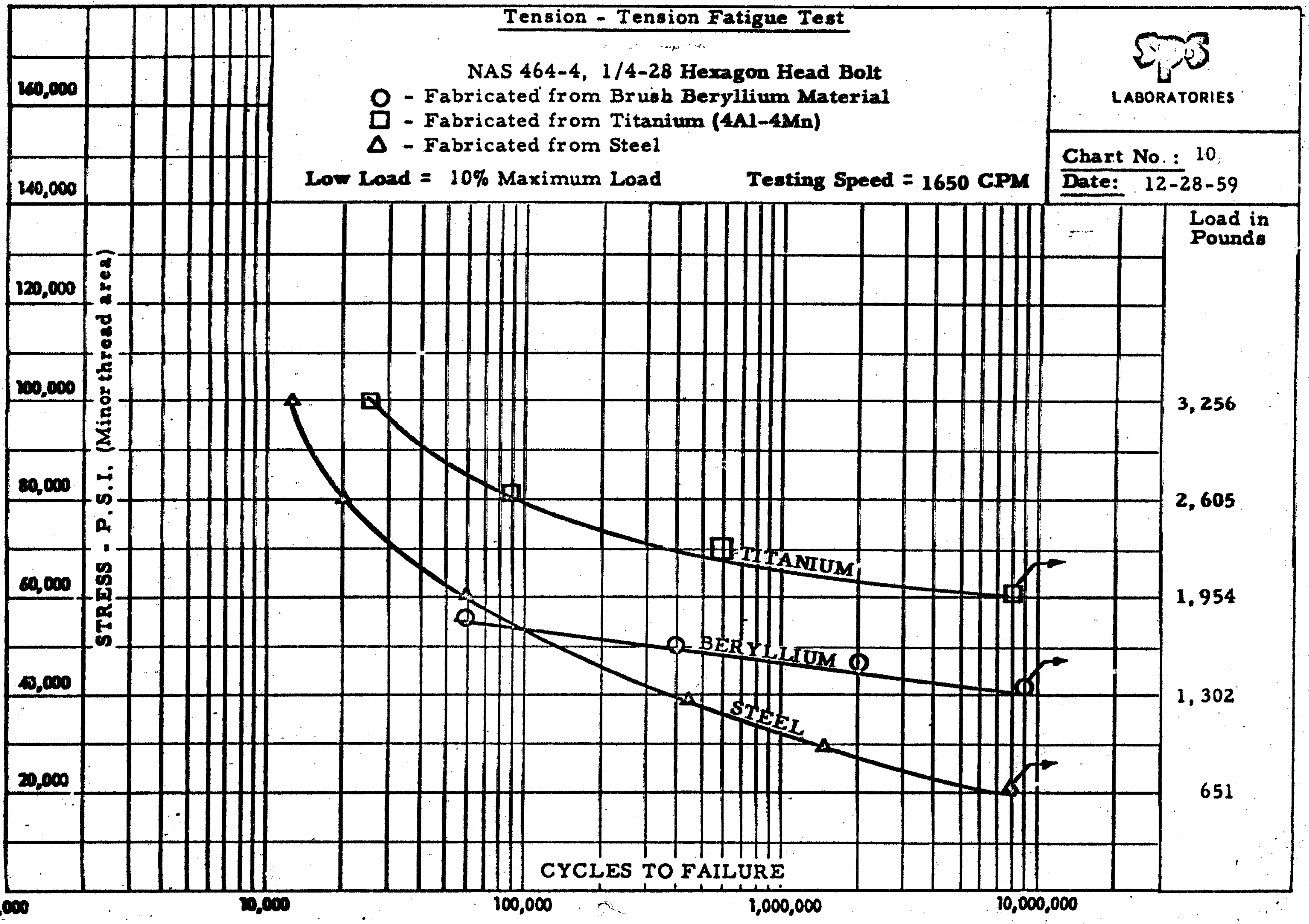
NAS 464-4, 1/4-28 Hexagon Head Bolts
Comparison on Stress Per Density Basis
○ - Fabricated from Brush Beryllium Material
□ - Fabricated from Titanium (4Al-4Mn)
△ - Fabricated from Steel
Low Load = 10% Maximum Load

LABORATORIES

Chart No.: 8
Date: 12-28-59




Tension - Tension Fatigue Test
NAS 464-5L, 5/16-24 Hexagon Head Bolts
○ - Fabricated from Beryllium Corporation Material
□ - Fabricated from Titanium (4Al-4Mn)
Δ - Fabricated from Steel
Low Load = 10% Maximum Load
Testing Speed =1650 CPM
LABORATORIES
Chart No.: 9
Date: 12-28-59
Load in Pounds
5, 242
4, 194
3, 145
2, 097
1, 048
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
STRESS - P. S. I. (Minor thread area)
TITANIUM
BERYLLIUM
STEEL
CYCLES TO FAILURE
1,000
10,000
100,000
1,000,000
10,000,000

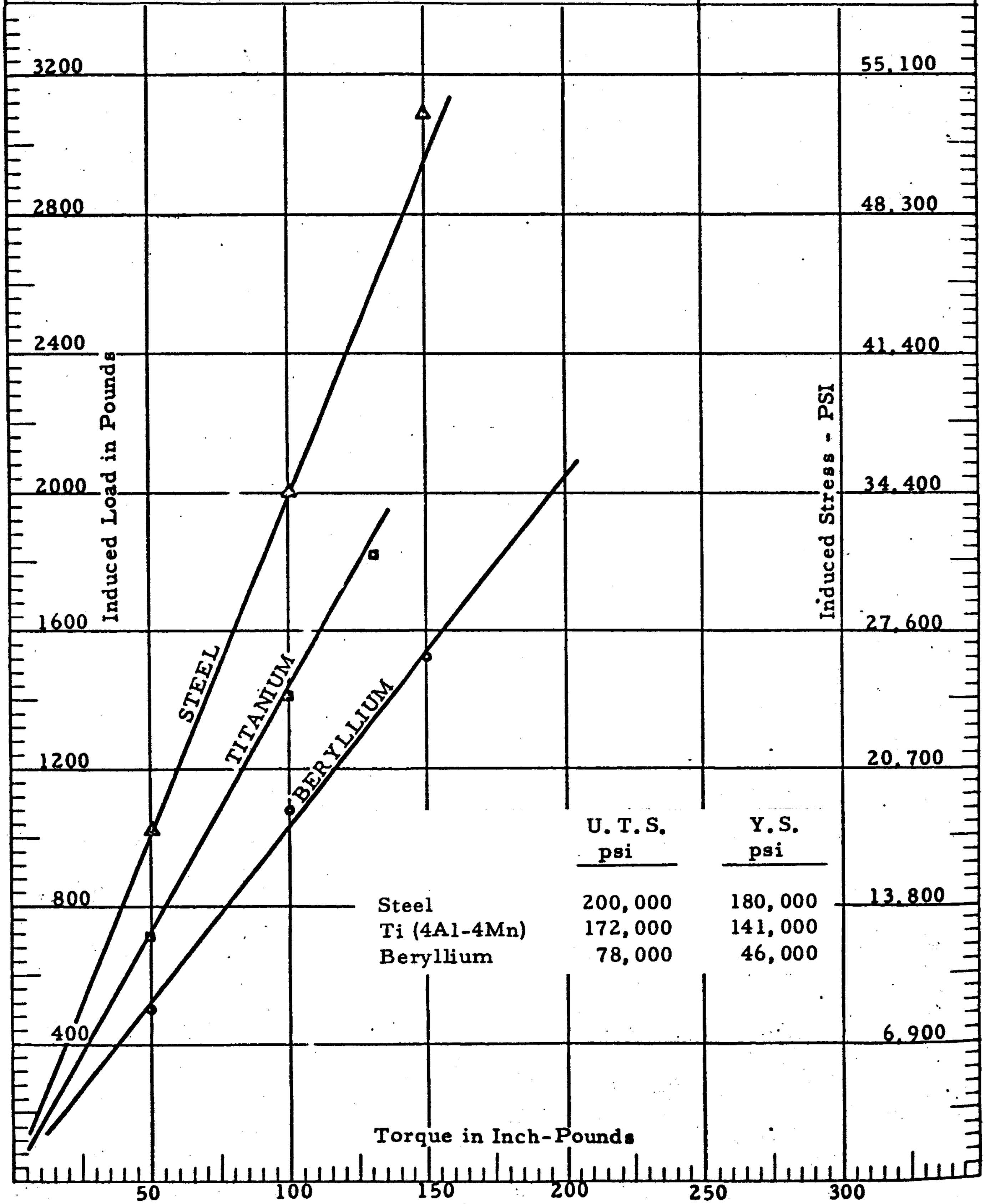

Tension - Tension Fatigue Test
NAS 464-4, 1/4-28 Hexagon Head Bolt
O - Fabricated from Brush Beryllium Material
□ - Fabricated from Titanium (4Al-4Mn)
Δ - Fabricated from Steel
Low Load = 10% Maximum Load
Testing Speed = 1650 CPM
LABORATORIES
Chart No.: 10
Date: 12-28-59
Load in Pounds
3,256
2,605
1,954
1,302
651
STRESS - P.S.I. (Minor thread area)
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
TITANIUM
BERYLLIUM
STEEL
CYCLES TO FAILURE
1,000
10,000
100,000
1,000,000
10,000,000

TORQUE-TENSION CURVE

NAS 464-5L, 5/16-24 Hexagon Head Bolt
FN 12-054, 5/16-24 Cadmium Plated Hexagon Nut
○ - Fabricated from Beryllium Corporation Material
□ - Fabricated from Titanium (4Al-4Mn)
△ - Fabricated from Steel

SPS LABORATORIES

Chart No.: 11
Date: 12-28-59



	U.T.S. psi	Y.S. psi
Steel	200,000	180,000
Ti (4Al-4Mn)	172,000	141,000
Beryllium	78,000	46,000

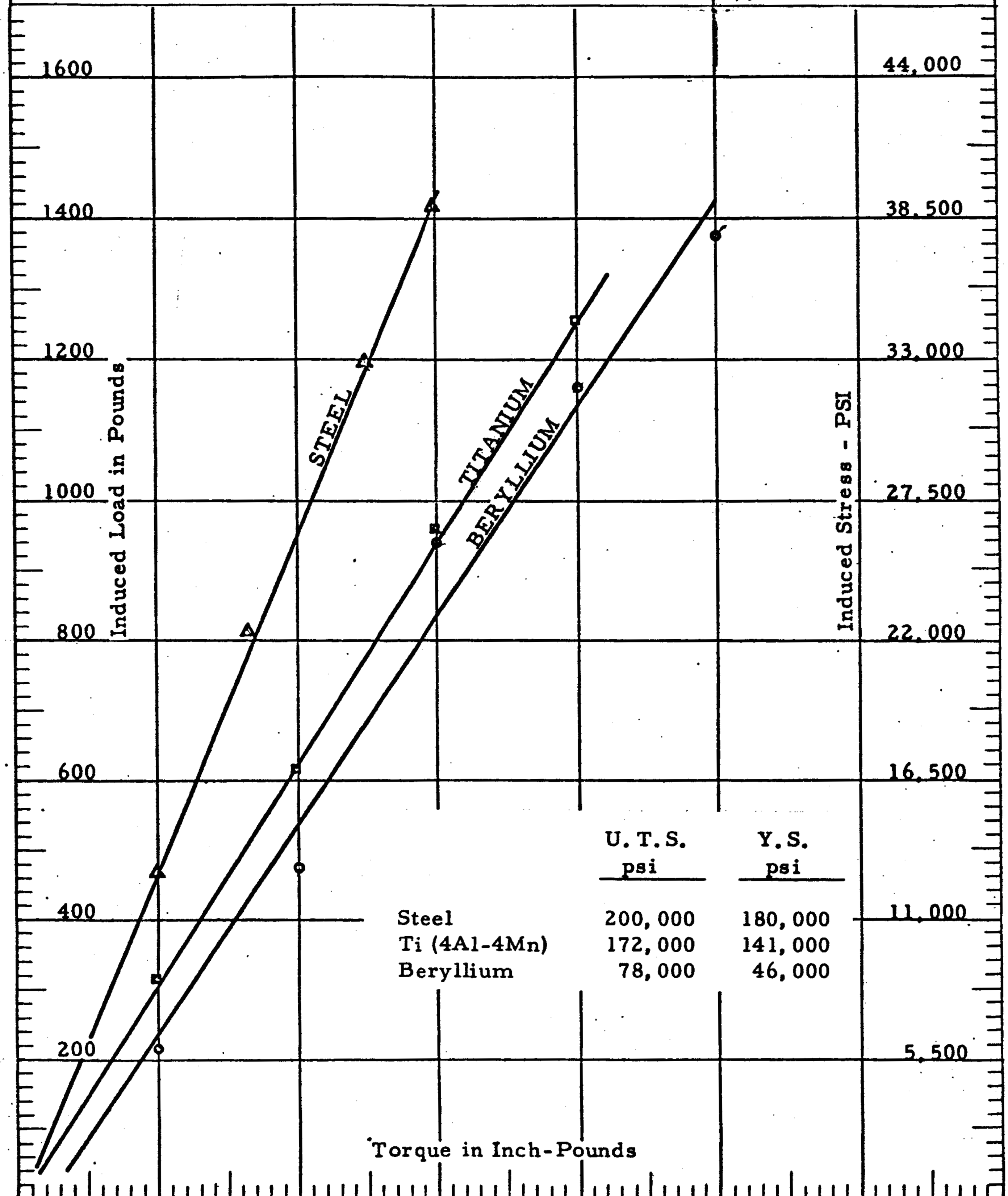
TORQUE-TENSION CURVE

NAS 464-4, 1/4-28 Hexagon Head Bolt
FN 12-048, 1/4-28 Cadmium Plated Hexagon Nut

○ - Fabricated from Brush Beryllium Material
□ - Fabricated from Titanium (4Al-4Mn)
△ - Fabricated from Steel

SPS LABORATORIES

Chart No.: 12
Date: 12-28-59



	U.T.S. psi	Y.S. psi
Steel	200,000	180,000
Ti (4Al-4Mn)	172,000	141,000
Beryllium	78,000	46,000